NASA Contractor Report 3776

CDTI Target Selection Criteria

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TABLE OF SYMBOLS

ALT = altitude

AZ = azimuth angle from radar relative to north

$B_i(R_k)$ = number of radar scans for which the range to the closest aircraft is less than range R_k

C = constant defined in Figure 2.4

C_i = number of radar scans in which aircraft i appears

$F_i(R_k)$ = function of R_k defined by eq. 4.1

G = acceleration of gravity

N = number of aircraft

R = relative range

$\dot{R}$ = relative range rate (closing velocity)

$\ddot{R}$ = relative range acceleration

$R_i(t)$ = range to closest aircraft relative to aircraft i

R_k = selected constant value of relative range

R_o = magnitude of miss distance

$\bar{r}$ = relative range vector

$\bar{r}_o$ = miss distance vector

U = acceleration parameter

V = magnitude of relative velocity

V_c = relative closing velocity

V_n = normal velocity magnitude

V_{nk} = selected constant value of normal velocity (V_n) magnitude

$\bar{v}$ = velocity vector

T = true time to closest approach for non-accelerated flight

t = time variable

τ = Tau parameter (time to closest approach for non-accelerating collision course)

τ_k = selected constant value of Tau (τ) parameter

τ_m = modified tau parameter

τ_{mk} = selected constant value of modified tau (τ_m) parameter

X, Y, Z = rectangular coordinate designation

ACKNOWLEDGMENT

1.0 INTRODUCTION AND SUMMARY

A Cockpit Display of Traffic Information (CDTI) is a cockpit instrument which provides information to the aircrew on the relative location of aircraft traffic in the vicinity of their aircraft (ownship). In addition, the CDTI may provide information to assist in navigation and in aircraft control. It is usually anticipated that the CDTI will be integrated with a horizontal situation indicator used for navigational purposes and/or with a weather radar display.

In order to properly evaluate and develop preliminary designs of the CDTI, it is necessary to determine the criteria to be used for selecting targets for display and the effect of various target selection criteria on the number of aircraft to be displayed. Airborne equipment, as well as the data link to the CDTI, will be strongly impacted by the peak and average number of targets to be displayed on the instrument.

Many of the technical issues associated with the CDTI concept depend strongly on the target selection criteria used. For example, the workload associated with monitoring the CDTI will be directly affected by the target selection criteria used. To minimize workload, it would be desirable to use narrow selection criteria to eliminate those aircraft with which the aircrew of ownship would not normally be concerned. However, the selection criteria cannot be made so narrow that the aircrew could not detect an ATC system error should it occur.

Previous efforts associated with airborne collision-hazard warning techniques are useful in defining criteria to be evaluated. The criteria used for CDTI, however, are somewhat different from those used in collision avoidance studies in that the collision avoidance criteria are concerned with predicting intersections of flight paths whereas the CDTI criteria are broader. For CDTI, an aircraft may be of interest even though it does not present a hazard.

Collision avoidance techniques can be used, however, by redefining the hazard region to encompass a much larger volume around the ownship. For example, the Modified Tau criterion used in collision avoidance is based on the following philosophy: one considers any aircraft a hazard if it is possible for the aircraft involved to collide within a designated time if each aircraft makes the worst possible maneuver. This criterion can be modified to apply to CDTI by making the time much larger than is usually considered in collision avoidance systems.

Target selection criteria evaluated in this study include the Modified Tau criteria, time-to-closest-approach (Tau), altitude bands, range only, and closing velocity. The approach initially used to evaluate these criteria was to generate a data base using the NASA/RTI terminal area air traffic model (TAATM). This model was used to generate a representative aircraft traffic sample for statistical analysis of the target selection criteria. In addition, actual radar (ARTS III) traffic data were obtained from the Atlanta and Miami terminal areas for evaluation. These radar data tapes were reduced and edited to the same format as the simulated data and analyzed using the same statistical analysis program as used for the simulated data. In general, results from the actual data compared favorably with results from the simulated data. The simulated data, however, was somewhat more ordered and more closely controlled than the actual data, as may be seen by examining statistical distributions of the average range to the closest aircraft from ownship (Figs 5.1 and 7.1 - 7.4).

The major results of the study are given in Section 5.0 (simulated data) and 7.0 (radar data). Plots are given showing the average percent of flying time (or probability) that a randomly selected aircraft in the terminal area with a CDTI will display a given number of other aircraft simultaneously for a given range setting. Plots are provided for all of the discrimination criteria investigated.

As an example of the type of results found in Section 5.0, Table 1.1 shows the number of aircraft displayed for a 10 n. mi. range setting on the CDTI and for various discrimination criteria. The numbers represent averages taken over each aircraft in the population using the analytical techniques described in Section 4.0. As may be seen from this example table, proper selection of

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discrimination techniques can considerably reduce the number of aircraft displayed and hence reduce the attention that must be given the display by the crew. Plus or minus 1,000 foot altitude discrimination effectively reduces the maximum number of aircraft displayed from ≈ 10 to ≈ 6. The Tau and Modified Tau discrimination criteria have the advantage of reducing the number of aircraft displayed more or less independently of the range setting on the display. Using a Tau criteria of $\tau < 120$ secs., the maximum number of aircraft displayed at this range setting would be reduced to three and the maximum of two aircraft would be displayed $\approx 10\%$ of the flying time in the terminal area.

TABLE 1.1
No. of Aircraft Displayed for 10 n.mi.
Range Setting on CDTI (Simulated Data)

Discrimination Criteria	Max. No. of Aircraft	10% of Flying Time	50% of Flying Time
Range Only	>10	10	5
Plus/minus 2,000 ft alt	9	5	2
Plus/minus 1,000 ft alt	6	4	2
Closing Vel > 0	10	7	3
Tau < 240 secs	5	4	2
Tau < 180 secs	5	3	2
Tau < 120 secs	3	2	1
Mod Tau < 120 secs	> 5	> 5	3
Mod Tau < 60 secs	6	4	2

Examples of the results obtained from the radar traffic tapes are shown in Tables 1.2 (Atlanta #1) and 1.3 (Miami #1). These tables are similar to table 1.1 in that they show the calculated number of aircraft that would be displayed on a CDTI using a 10 n. mi. range setting under the conditions found in the data. Numbers are provided showing the maximum aircraft displayed, the number displayed approximately 10% of the flying time and the number displayed approximately 50% of the flying time, on the average. Tables for other CDTI ranges can be constructed using the data in sections 5.0 and 7.0.

A major conclusion that can be drawn from the data provided in this report is that in high density terminal areas, aircraft equipped with a CDTI with range setting on the order of 8-10 n.mi. will not observe more than 10 targets on the display for any length of time, even with no discrimination. With altitude discrimination of +/- 2000 ft., the number of targets displayed will rarely exceed 5, and for over 50% of the time will be on the order of 1 or 2.

Closing velocity discrimination appears to have no clear advantages over altitude discrimination except for those cases where relative altitude information may not be available (e.g. lack of Mode C transponder). In this case, closing velocity discrimination could reduce clutter due to unwanted targets.

Use of the Tau or Modified Tau criterion to provide a hazard or attention alarm in conjunction with a CDTI could lead to a severe false and multiple alarm situation unless the alarm threshold is set at small values of Tau (<60 secs.) or Modified Tau (<25 secs.). Even with these settings, the data indicate that alarms will occur frequently.

The following section discusses the generation of the stimulated data base from the TAATM model. Section 4 discusses the techniques for statistical analysis of the target selection criteria and Section 5 gives the results from the evaluation of the criteria using the simulated data base. Section 6 discusses the ARTS radar data base and section 7 gives the results of the evaluation using the four radar traffic tapes from the Miami and Atlanta terminal areas.

TABLE 1.2
No. of Aircraft Displayed for 10 n.mi.
Range Setting on CDTI (Atl. #1 radar data)

Discrimination Criteria	Max. No. of Aircraft	10% of Flying Time	50% of Flying Time
Range Only	>10	7	2
Plus/minus 2,000 ft alt	7	3	<1
Plus/minus 1,000 ft alt	4	2	<1
Closing Vel > 0	10	4	2
Tau <240 secs*	>10	6	2
Tau <180 secs*	9	4	2
Tau <120 secs*	5	2	<1
Mod Tau <120 secs*	>10	>10	5
Mod Tau <60 secs*	7	3	<1

*See note at bottom of Table 1.3 (next page)

Table 1.3
No. of Aircraft Displayed for 10 n.mi.
Range Setting on CDTI (Miami # 1 Data)

Discrimination Criteria	Max No. of Aircraft	10% of Flying Time	50% of Flying Time
Range Only	>10	10	3
Plus/minus 2,000 ft alt.	>10	6	1
Plus/minus 1,000 ft alt.	9	3	<1
Closing velocity > 0	>10	6	2
Tau <240 secs*	>10	8	3
Tau <180 secs*	>10	5	2
Tau <120 secs*	9	3	1
Mod Tau <120 secs*	>10	10	7
Mod Tau <60 secs*	10	4	1

*Note: These numbers are for long ($\approx$ 50 n. mi.) CDTI range settings instead of a 10 n. mi. setting. Tau discriminates are not a strong function of range but obviously use of this parameter could not result in a display of more aircraft than the "range only" numbers.

2.0 TARGET SELECTION CRITERIA

2.1. General Discussion

A target selection criterion, usually expressed as a mathematical relationship between measurable parameters, is a means by which aircraft which are not of interest to the crew can be eliminated from the display. With proper selection criteria, the clutter on the CDTI can be reduced and crew attention required in monitoring the display minimized. To minimize the aircraft on the display, certain "filtering" parameters can be used to eliminate those aircraft which may not be of interest. For example, the filtering parameters can be used to eliminate aircraft which are not considered hazardous to the ownship, with the hazard defined in different ways.

To define a hazardous aircraft, it is desirable to know first of all if the two aircraft involved could possibly collide or be involved in a near-miss situation. In addition, to be useful, the hazard indicator must be measurable with existing data available in the ownship. Usually a measure or range, altitude and range rate can be used to define a potentially hazardous aircraft and also provide additional information such as the urgency of the hazard.

The target selection criteria that have been investigated include:

1.   Display all aircraft within a given range (no filtering of non-hazardous aircraft).

2.   Display all aircraft within selected altitude bands.

3.   Display only aircraft with a positive closing velocity.

4.   Display only aircraft with a time to closest approach less than a selected time (Tau filtering).

5.   Display only aircraft with a selected time to closest approach modified with a range criteria (Modified Tau).

Filtering parameters used in investigating the above criteria are discussed in the following.

2.2. Altitude Discrimination

In using altitude discrimination for target selection, only aircraft within a given altitude band about the ownship are displayed on the CDTI. This discrimination technique is expressed mathematically as:

$$|\Delta h| \overline{<} K \tag{2.1}$$

Where: Δh = Measured altitude difference between ownship
and target aircraft (ft)

   K = Selected constant (ft)

2.3 Closing Velocity Discrimination

In using this discrimination technique, only aircraft with a positive closing velocity (converging aircraft) are included on the display. This technique requires derivation of relative range-rate between the ownship and target aircraft. The mathematical expression for this discrimination technique is:

$$\dot{R} \geq 0 \tag{2.2}$$

Where: $\dot{R}$ = Relative range-rate between ownship and target (kts)

2.4 Time-to-Closest-Approach Discrimination (TAU)

The TAU criteria is based on the assumption of straight line flight paths for both the ownship and target aircraft. Figure 2.1 shows an encounter situation between two unaccelerated aircraft. The position of the protected and intruding aircraft are the points P_1 and P_2, respectively. The dotted aircraft represent the positions at some time later at which time the aircraft are at their point of closest approach. $\bar{v}_1$ and $\bar{v}_2$ are velocity vectors for the aircraft and $\bar{r}$ represents the relative range vector. The relative velocity $\bar{v}_1 - \bar{v}_2$ is represented by the vector $\bar{v}$. The projected miss distance, assuming nonaccelerating flight, will be the quantity $\bar{r}_o$. It can be seen from the figure that, for closing flight paths,

$$R_o^2 = R^2 - (VT)^2, \tag{2.3}$$

where $|\bar{r}(t)| = R$, $|\bar{r}_o| = R_o$, $|\bar{v}| = V$, and T is the time-to-closest approach. The projected miss distance (R_o) can be written in terms of the relative

MISS DISTANCE $\bar{r}_0$

$\bar{v} = \bar{v}_1 - \bar{v}_2$

$$|\bar{r}_0|^2 = |\bar{r}|^2 - |\bar{v}T|^2$$
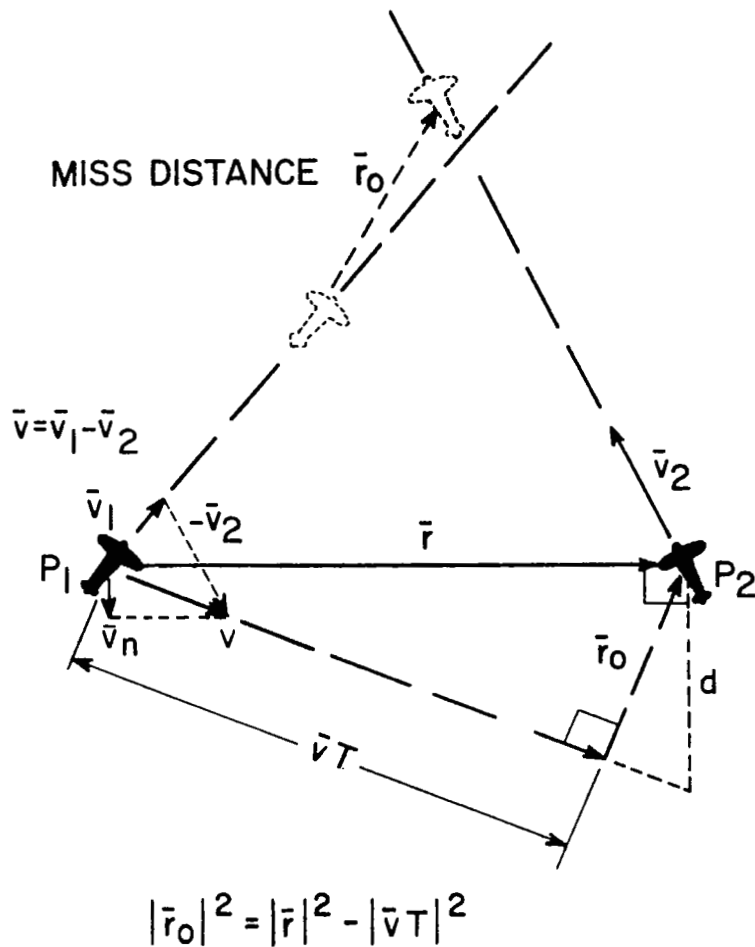
Figure 2.1.   Two-aircraft geometry for unaccelerated flight.
Here $\bar{r}_0$ is the projected miss distance and has
a magnitude from the equation shown. The geometry
has been chosen such that range rate is positive
for decreasing range, and range acceleration is
positive for decreasing range rate.

range and its derivatives by noting that R_o and V are constants, differentiating R twice in Equation 2.3 and substituting for T and V to obtain:

$$R_o^2 = \frac{R^3 \ddot{R}}{\ddot{R} R + \dot{R}^2}$$ (2.4)

Similarly, the time-to-closest-approach (T) is obtained from Equation 2.3 and the derivatives of range as:

$$T = \frac{R \dot{R}}{\ddot{R} R + \dot{R}^2}$$ (2.5)

Note that for a true collision course, $\ddot{R} = 0$ and Equation 2.5 is reduced to

$$\tau = R/\dot{R}$$ (2.6)

Where τ (TAU) is the time-to-collision.

The TAU discrimination used for target selection is therefore defined as:

$$R/\dot{R} \leq \tau_k$$ (2.7)

Where τ_k is a selected constant (secs).

2.5 Modified TAU Discrimination

A realistic hazard indicating criterion is developed in reference (1) that is intuitively appealing. This criterion is based on the following philosophy: one considers any aircraft a hazard if it is _possible_ for the aircrafts involved to collide within a designated time τ_{mk} if each aircraft makes the _worst possible_ maneuver. Since aircraft maneuvers have definite acceleration limits, an acceleration constraint can be used to define a set of possible maneuvers.

It can be shown that the set of all aircraft that can reach a protected craft's position in a time less than a given time τ_{mk}, using a relative acceleration no greater than a given acceleration U, have values of relative range (R), closing velocity ($\dot{R}$), and normal velocity (V_n), which satisfy the equation

$$(R - \dot{R}t)^2 + V_n^2 t^2 = U^2 t^4/4$$ (2.8)

for some t between 0 and τ_{mk}. The hazard volume in the R, R. V_n space defined by Equation 2.8 is shown in Figure 2.2. From the figure, it can be seen that points within the volume will also be contained in a volume defined by:

$$R - \dot{R}\,\tau_{mk} < \frac{U\tau_{mk}^2}{2} \tag{2.9}$$

which uses range (R) and range rate (R) only. The criteria given by Equation 2.9 thus provides an approximation to the region defined by Equation 2.8, and leads to a hazard criterion designated as the "Modified Tau" criterion, with a hazard defined by $\tau_m < \tau_{mk}$ where

$$\tau_m = \frac{-\dot{R} + (\dot{R}^2 + 2UR)^{1/2}}{U} \tag{2.10}$$

τ_{mk} and U are selected constants (Note: In this study U = 1/4 g).

2.6 The Hazard Region Concept

The discrimination afforded by the selection criteria discussed above can be visualized graphically by plotting the selection region on a range-range rate plot. For example, Figure 2.3 shows the selection region in the range-range rate plane defined by the Tau discrimination criteria.

Figure 2.4 shows the selection region defined by the Modified Tau criteria. As may be seen, the Modified Tau criteria would select targets with zero closing velocity, but which are within a range defined by the selected constants. Thus, this criterion is useful for parallel approaches in that aircraft would be displayed on a parallel, non-closing trajectory.

It should be noted that in the range-range rate plane, any potentially hazardous trajectory between two aircraft must follow a line in the upper left-hand quadrant of the range-range rate plot. A hazardous relative trajectory moves from right to left in this quadrant.

Exact region defined by eq. 2.8

R/U(SEC.^{2})

PLANE DEFINED BY

$$R - \dot{R}\tau_{mk} = \frac{U\tau_{mk}^2}{2}$$

60

30

V_n/U (SEC)

$\tau_m < \tau_{mk}$; $V_n < V_{nk}$ APPROXIMATION TO THE HAZARD REGION WHERE

$$V_{nk} = \frac{U\tau_{mk}}{2}$$

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R/U (SEC)
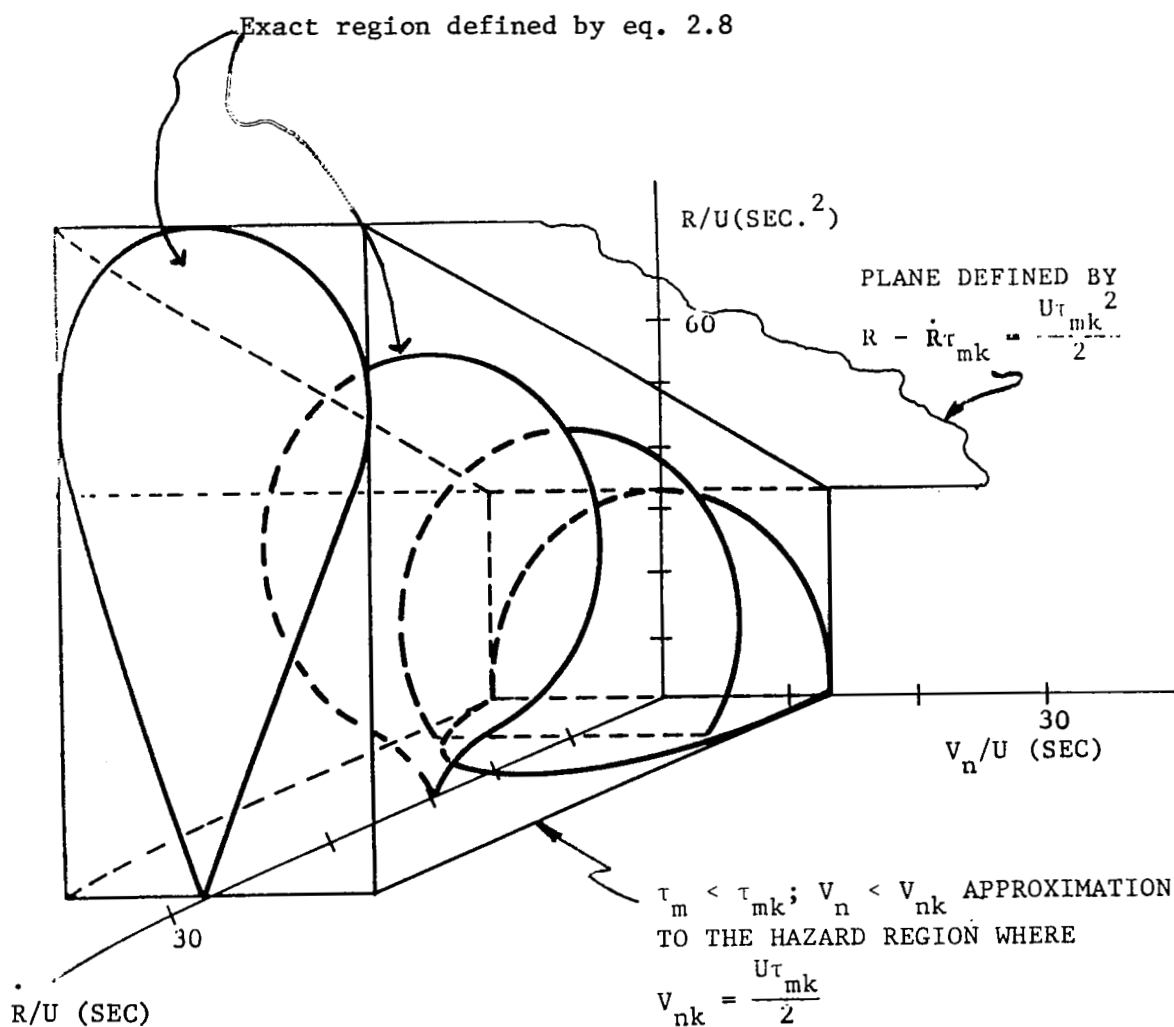
Region plotted for τ_{mk} = 25 sec.

Figure 2.2. Hazard volume defined by eq. 2.8. Approximations to the volume given by eqs. 2.9 and 2.10 are also shown. (From reference (1))
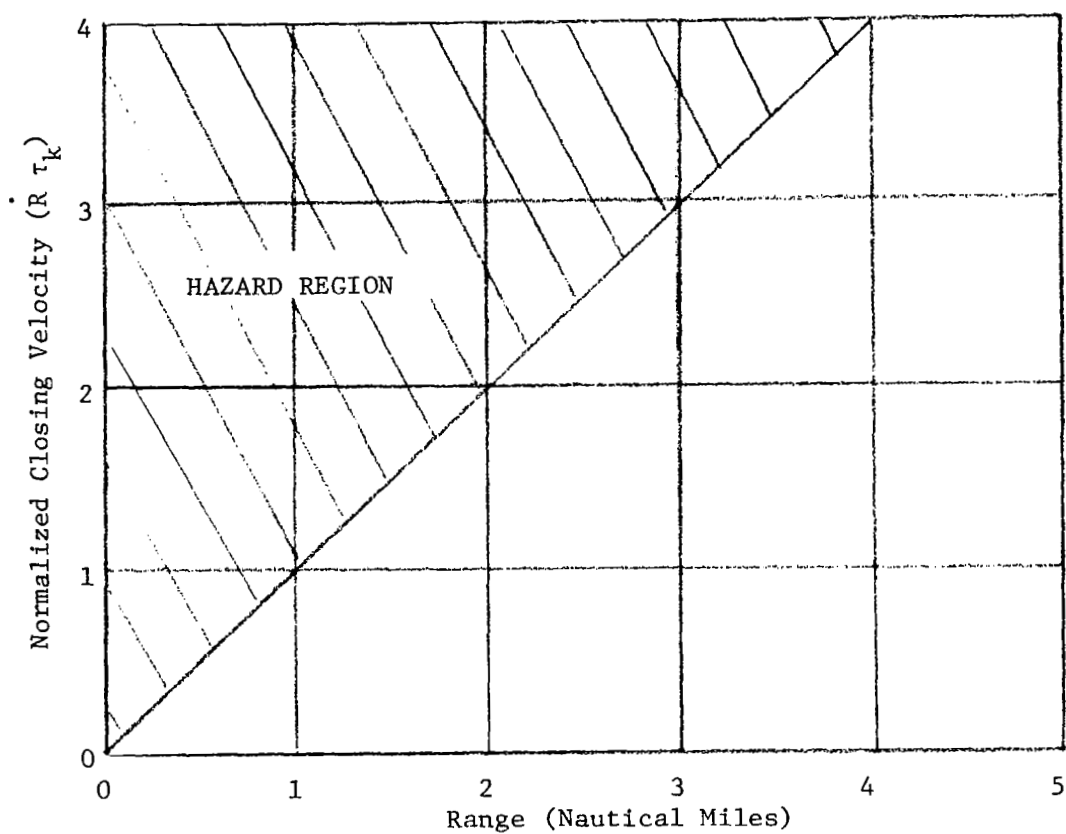
Figure 2.3.   Hazard region in the range, range rate plane defined by the
              Tau criteria ($R/\dot{R} < \tau_k$).
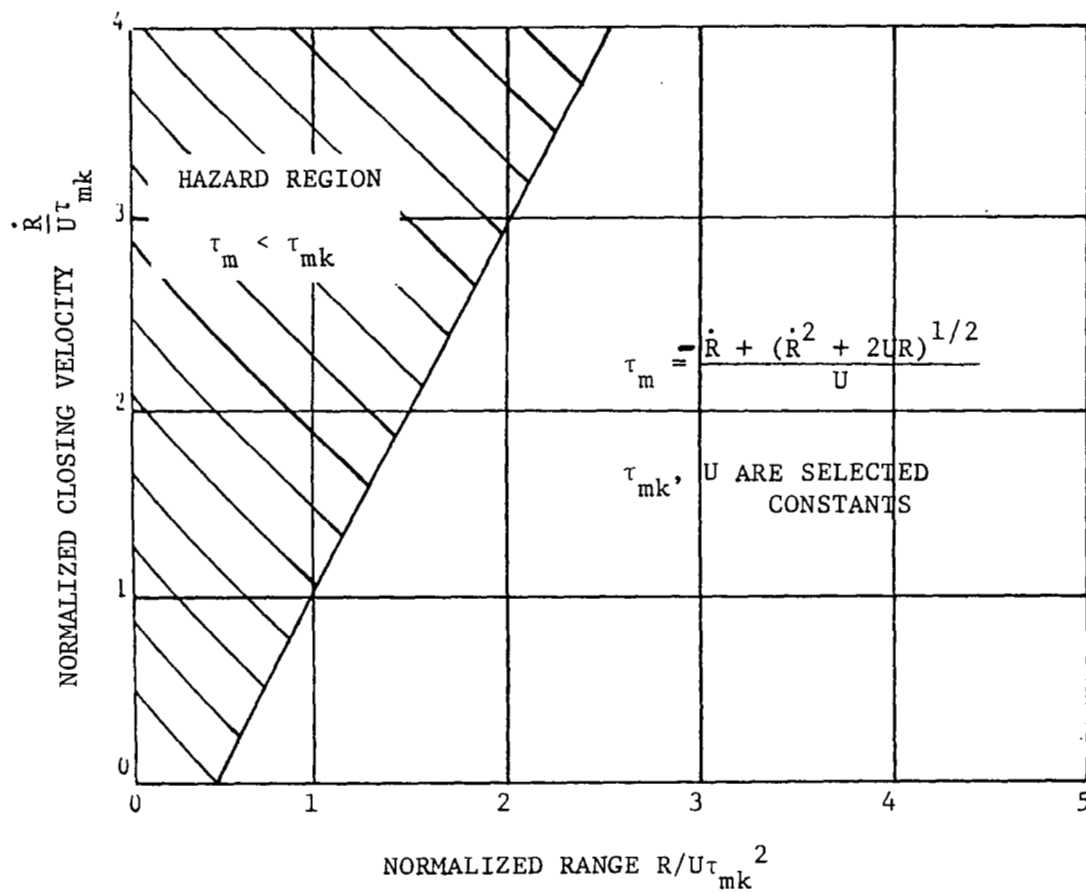
Figure 2.4. Hazard region in the range, range rate plane defined by the modified tau criteria. Note that the region is also defined by $(R-C)/\dot{R} < \tau_{mk}$ where $C = U\tau_{mk}^2/2$.

3.0 DATA BASE

The RTI/ NASA Terminal Area Air Traffic Model (TAATM) was used to generate representative aircraft traffic samples for statistical analysis. TAATM is a flexible simulation of the airborne, ground control and communication aspects of the terminal area which is, with input data changes, adaptable to existing terminal areas and which can be and is being expanded to incorporate advanced concepts of instrumentation and control. The airborne aspects modelled include aircraft dynamics, performance capabilities of twenty different classes of aircraft, traffic samples depending on both desired operations per hour and probabilities of aircraft types and route loadings, aircraft load factors, intended flight plans, flight path errors, and meteorological effects. The ground control aspects include control procedures (both current air traffic control procedures and advanced control techniques), control options (e.g., speed control, alternate paths, altitude change, holding patterns), separation standards navigational aids, terminal area geometrics, air-route structuring, runway handling constraints and surveillance errors. The communication aspects reflect controller to pilot communication and include message content, delays associated with the actual delivery of a message, delays associated with controller work load and priority delivery of messages.

The TAATM model, which can be run in both a real-time or a fast-time mode, outputs overall performance measures for trade-off evaluation of various navigational and control techniques, as they relate to the terminal environment as a whole. In addition, the real-time mode offers a visual and audio environment for a realistic real-time simulation of traffic in the terminal area and is capable of providing automatic guidance information to piloted simulated aircraft. The overall TAATM model is composed of three independent units, including a traffic generation program, the terminal area simulation, and post-analysis routines. These programs are described in references 2 and 3. A typical TAATM display of traffic is shown in Figure 3.1.

TAATM was configured to represent the Atlanta terminal area under present-day operating conditions. A 2-hour simulated data base was generated providing the following traffic for analysis:

TERMINAL AREA SIMULATION
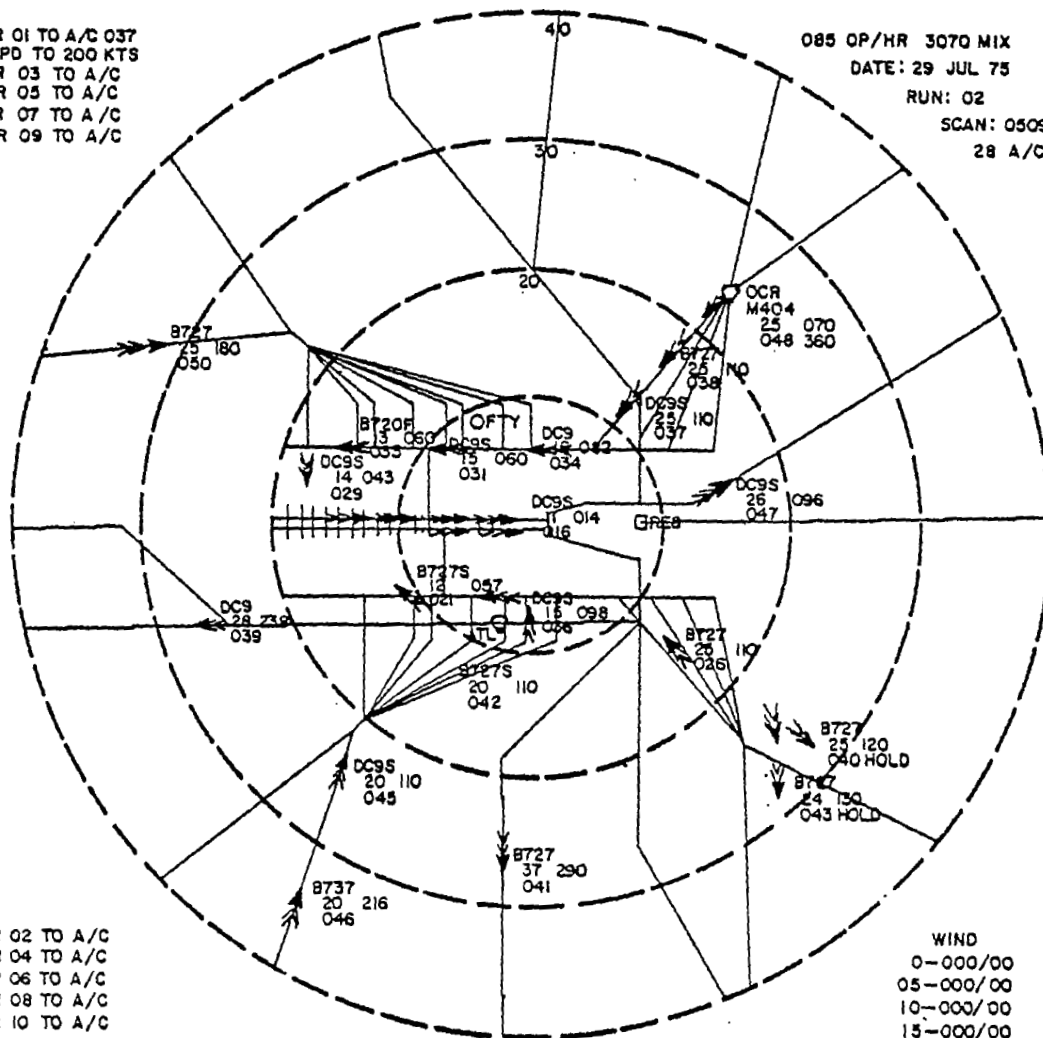
Figure 3.1. Typical TAATM display output (Atlanta).

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Terminal: Atlanta

Simulated Time Period: 2 Hours

Traffic Mix: 70/30 Arrival/Departure Ratio

Scheduled Operation Rate: Approx. 70 Ops/Hour

Average Flight Time, Arrivals: 25.25 Min.

Average Flight Time, Departures: 11.24 Min.

Average Time Between Touchdowns: 72.24 Secs.

Average Time Between Departures: 157.12 Secs.

Average Departure Delay: 26 Min.

Average Arrival Delay: 2.6 Min.

Actual Arrivals: 99

Actual Departures: 51

Figure 3.2 shows a plot of the aircraft traffic with the position of each aircraft plotted at intervals of approximately 40 seconds. This plot may be compared with similar plots from actual radar data tapes in Figs 6.3 through 6.7.
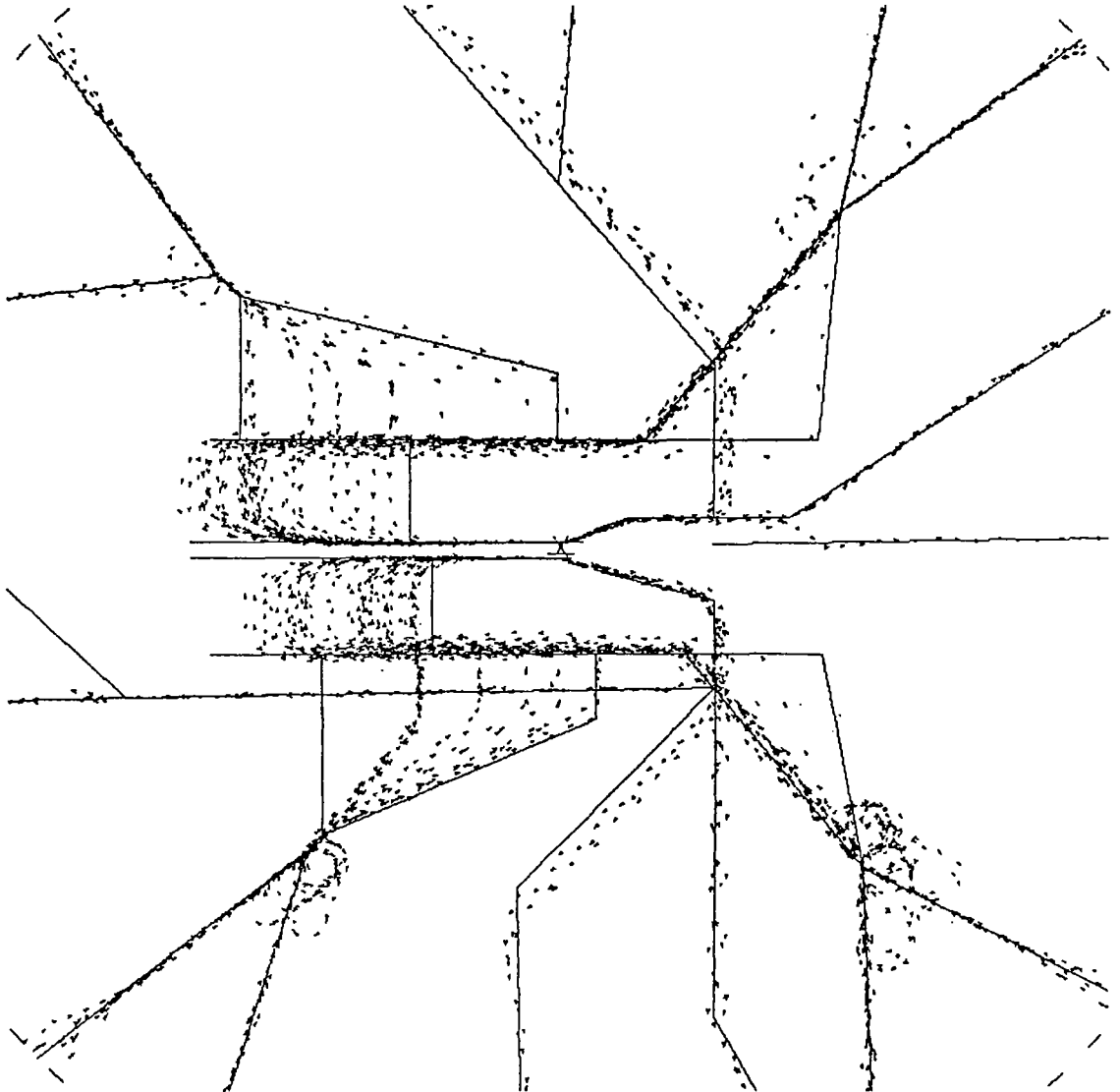
Figure 3.2   Plot of initial data set generated from TAATM.   The position
              of the aircraft in the data set are plotted at approximately
              40 second intervals.

4.0 ANALYSIS OF TRAFFIC DATA

4.1. General Technique

Techniques for analysis of traffic data are given in reference 4. To illustrate the techniques involved, consider the estimation of a statistic such as "the average percentage of flying time that a randomly selected aircraft will find one or more aircraft within a given range."

Let $R_i(t)$ denote the range of the closes aircraft relative to a particular aircraft i. Figure 4.1 shows a hypothetical plot of a sample $R_i(t)$ function.
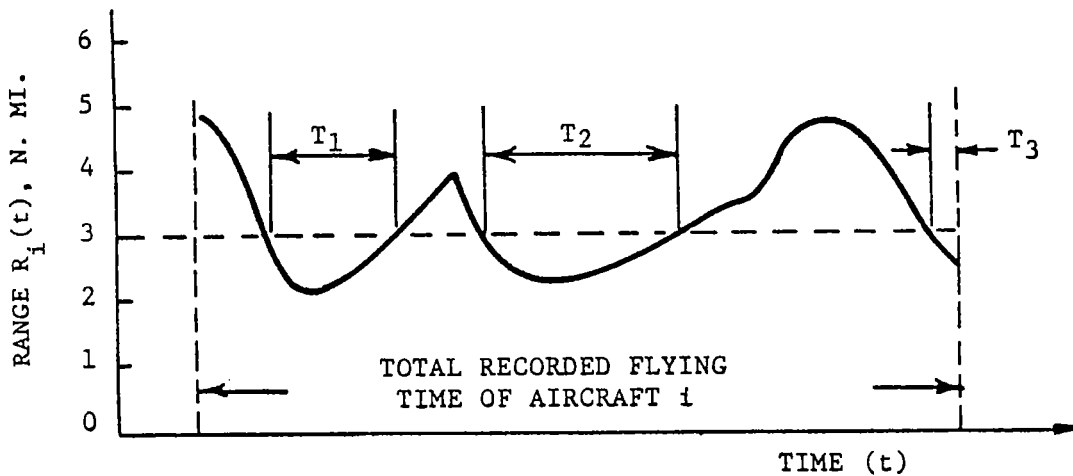
Figure 4.1. Hypothetical plot of a sample function.
$R_i(t)$ is the range to the closest aircraft relative to aircraft i.

The fraction of the flying time of aircraft i that $R_i(t)$ is less than a selected constant value, R_k, is then given by:

$$F_i(R_k) = \frac{\text{time that } R_i(t) \text{ is less than } R_k}{\text{flying time of aircraft } i} = \frac{B_i(R_k)}{C_i} \qquad (4.1)$$

where C_i is the number of radar scans in which aircraft i appears and $B_i(R_k)$ is the number of radar scans for which $R_i(t)$ is less than R_k.

In Figure 4.1 a specific R_i of 3 miles is shown and the function $B_i(3)$ is given by the sum of the times designated as T_1, T_2, and T_3 in the figure. To retain the largest amount of information in the calculations, the numerical threshold (e.g., R_k in this example) is considered a parameter, and distributions are formed as a function of the value of the parameter.

Under the assumption that $R_i(t)$ is a stationary process, $F_i(R_k)$ provides an estimate of the probability that aircraft i will have another aircraft within a range R_k at any particular instant of time during the flight time of aircraft i.

Considering all aircraft in the data base, a weighted average (i.e., contribution of average is proportional to sample size) over all aircraft provides an unbiased estimate of the probability that a randomly chosen aircraft i will find another within a range of R_k. This calculation is:

$$\Pr(R_i(t) < R_k) = \frac{1}{n} \sum_{i=1}^{n} \frac{B_i(R_k)}{C_i} \left[\frac{C_i}{\frac{1}{n} \sum_{i=1}^{n} C_i} \right] = \frac{\sum_{i=1}^{n} B_i(R_k)}{\sum_{i=1}^{n} C_i} \qquad (4.2)$$

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where n is the number of aircraft and the weighting factor is:

$$\frac{c_i}{\frac{1}{n}\sum_{i=1}^{n}c_i} = \frac{\text{flying time of aircraft } i}{\text{average flying time of all aircraft}} \qquad (4.3)$$

Equation 4.2 also represents the average (weighted) fraction of flying time for which $R_i(t) < R_k$ for all aircraft in the data base.

In an exactly analogous manner, the calculation can be made for the kth closest aircraft to aircraft i, or for the other target selection criteria of interest.

The above probability calculations require slight modification in the derivation in case the sample function does not exist over a portion of the flying time of aircraft i (e.g., only one aircraft in the data). In any case, however, the end result given by Equation 4.2 is still valid. The derivation is modified by consideration of the conditional probability first, or the probability that aircraft i will have another aircraft within range R_k given that at least two aircraft are in the data. The condition on the probability that another aircraft is in the data with aircraft i, giving the same numerical result as is given by Equation 4.2.

4.2 Computer Programs.

An existing TAATM statistical analysis program was modified to provide the statistics necessary for the CDTI target selection criteria evaluation. The analysis program operates on the TAATM data output in the form of aircraft positions and velocities given at four second intervals throughout the duration of the data run. In addition, inputs are provided to designate the filtering parameter to be used as well as other supplementary information.

Outputs of the analysis program include the following:

1. Departure entry time, deletion time, and flight time.
2. Histogram of time between entries and take-off queue.
3. Histogram of actual time between departures (seconds).

4. Histogram of imposed delay in take-off queue (seconds).

5. Histogram of time between successive departures from the terminal area (seconds).

6. Histogram of actual flight time in terminal area for departures (minutes).

7. Histogram of total time in terminal area for departures (minutes).

8. Listing of arrival entry time, deletion time and flight time.

9. Histogram of time between entries in the enroute queue for arrivals (seconds).

10. Histogram of actual time between arrivals (seconds).

11. Histogram of proposed delay in enroute queue for arrivals (seconds).

12. Histogram of time between successive touchdowns (seconds).

13. Histogram of actual flight time in terminal area for arrivals (minutes).

14. Histogram of total time in terminal area for arrivals (minutes).

15. Histograms of relative range between aircraft (for 1 through 5 or 5 through 10 aircraft).

16. Histograms of Tau.

17. Histogram of Modified Tau.

In addition to the histogram listings above, the computer program has been modified to provide plots of the relative range, Tau, and Modified Tau histograms.

Supplementary plotting programs were developed to make plots of percentage of flying time versus range for various filtering parameters. Examples of output from the computer programs are given in the following section.

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5.0 EVALUATION OF SELECTION CRITERIA

5.1. Targets Displayed with No Discrimination.

From the analysis of the simulated data as discussed in the preceding section, it is possible to describe statistically the number of targets that will be seen on a CDTI with any value of range setting. For example, Figure 5.1 shows a probability distribution (histogram) of the probability that a randomly selected aircraft from the data base will have at least one other aircraft within the range bins given along the horizontal axis. This probability is equivalent to the percentage of total flying time in the terminal area that the selected aircraft will find at least one other aircraft within the range bins plotted. Thus, the vertical scale is labeled in percentage of flying time instead of probability.

Figure 5.2 shows a cumulative distribution of the probability of finding at least one aircraft within the range given along the horizontal axis. As an example of interpreting the cumulative plot, it can be seen that the average percent of flying time that a randomly selected aircraft found at least one other aircraft within a 5 nautical mile range was 60%. Again, this is the same as the probability that at any instant of time, a randomly selected aircraft would have at least one other aircraft within that range.

Similar histograms have been made for up to 10 simultaneous aircraft within range. Figure 5.3 shows the situation for 5 simultaneous aircraft within a range given along the horizontal axis. Figure 5.4 is the corresponding cumulative probability plot for 5 simultaneous aircraft within a given range. As may be seen from Figure 5.4, a randomly selected aircraft will have 5 simultaneous aircraft within a 10 nautical mile range for approximately 50% of the flying time in the terminal area.

The histogram data for the probability of observing from 1 to 10 aircraft are summarized in Figure 5.5. This plot gives the average percent of flying time that a randomly selected aircraft will have from 1 to 10 aircraft displayed within a range value given along the horizontal axis. This plot assumes no discrimination is used in the CDTI.

5.2. Displays with Altitude Discrimination.

Figure 5.6 summarizes the effect of using altitude discrimination with a plus or minus 1,000-foot altitude band as the discriminate. That is, only

aircraft are displayed within the slant range given on the plot and within
an altitude band of plus or minus 1,000 feet of the ownship are counted.
By comparison with Figure 5.5, the effectiveness of altitude discrimination
may be seen.

Figure 5.7 is a similar plot except for an altitude band of plus or
minus 2,000 feet about the ownship.

Figures 5.8 through 5.14 present the effect of altitude discrimination
in a different form. In these plots, the CDTI range setting is fixed and the
plot provides the probability of observing a given number of aircraft within
the given range with the number of aircraft plotted along the horizontal axis.
The altitude discrimination of plus or minus 1,000 feet and plus or minus
2,000 feet is compared with the data with no discrimination. These curves
show clearly the effectiveness of altitude discrimination in reducing the
number of targets that would be displayed with a given range setting. For
example, with plus or minus 2,000 feet altitude discrimination, no more than
9 aircraft appeared within a 10-mile range at any one time. With the plus or
minus 1,000-foot altitude band discrimination, no more than 6 aircraft appeared
within a 10-mile range simultaneously.

5.3. Closing Velocity Discrimination.

As discussed in Section 4.0, eliminating those aircraft that are not
closing on the ownship can provide a useful and easily implemented discriminate.
Figure 5.15 shows the cumulative probability plots for the data set counting
only closing aircraft (closing velocity greater than zero). Figures 5.16
through 5.22 provide comparisons of the average percent of flying time that a
given number of aircraft will be found within a given range for range values
from 5 to 25 nautical miles. As in the altitude plots, each plot provides a
comparison of the data with no additional discrimination and with the data using
closing velocity discrimination.

Closing velocity filtering appears to be more effective at larger range
scale settings and for larger number of aircraft within the given range. That is,
for a range setting of 5 nautical miles, the average percent of flying time that
one aircraft will be within range is reduced approximately 33% with closing
velocity filtering, whereas the average percent of flying time that 6 aircraft
will be within 12 nautical miles is reduced over 50%.

Comparison of the closing velocity discrimination with altitude discrimi-
nation indicates that in almost all cases, plus or minus 2,000-foot altitude

discrimination is more effective than closing velocity discrimination.
This may be seen by examining, for example, the range = 10 n. mi. plots
(Figures 5.10 and 5.18).

5.4. Time-to-Closest-Approach Discrimination.

Data runs were made using the collision-avoidance parameter Tau as a
discriminate with values of 240, 180, and 120 seconds. As may be expected,
this discriminate was very effective in reducing the number of aircraft
displayed at any given range setting.

Figures 5.23 through 5.25 summarize the cumulative probability distri-
butions for 1, 3 and 5 aircraft displayed and with various values of time-to-
closest-approach discrimination. Notice that the Tau discriminate tends to
keep the number of aircraft displayed constant regardless of the range
setting on the display. For example, the percentage curves for range = 10 are
similar to the percentage curves for range = 25. This is to be expected because
of the nature of the Tau parameter as discussed in Section 2 .

Figures 5.26 through 5.32 compare the effectiveness of the Tau discriminate
with the case with no discrimination for various CDTI range settings. The
tendency for the number of aircraft displayed using this discriminate to remain
constant regardless of the range setting is clearly evident in these plots.

5.5. Modified Time-to-Closest-Approach Discrimination.

Runs similar to those described in Section 5.4 were run using the Modified
Tau discriminate with values of 180, 120, and 60 seconds. The allowed
acceleration parameter was 1/2 G. Results for Modified Tau < 120 were essentially
the same as those for Modified Tau < 180, hence are not plotted.

Figures 5.33 and 5.34 show the cumulative probability distributions for the
case of 1, 3 and 5 aircraft and with two values of Modified Tau discrimination.
The Modified Tau parameter tends to keep the number of aircraft displayed
constant regardless of the range setting as in the case of the Tau parameter
discussed above. However, for equivalent number of seconds, more aircraft will
be displayed using Modified Tau than were displayed using Tau. This is to be
expected because the Modified Tau parameter allows more area coverage in the
range-range rate plane (see Figure 2.4).

Figures 5.41 through 5.42 show the effectiveness of the Modified Tau
discriminate for various CDTI range settings.

HISTOGRAM OF RELATIVE RANGE (NMI)

Figure 5.1 Histogram of the average percentage of flying time that a randomly selected aircraft will have at least one other aircraft within the range bins shown along the horizontal axis. No discrimination is used.
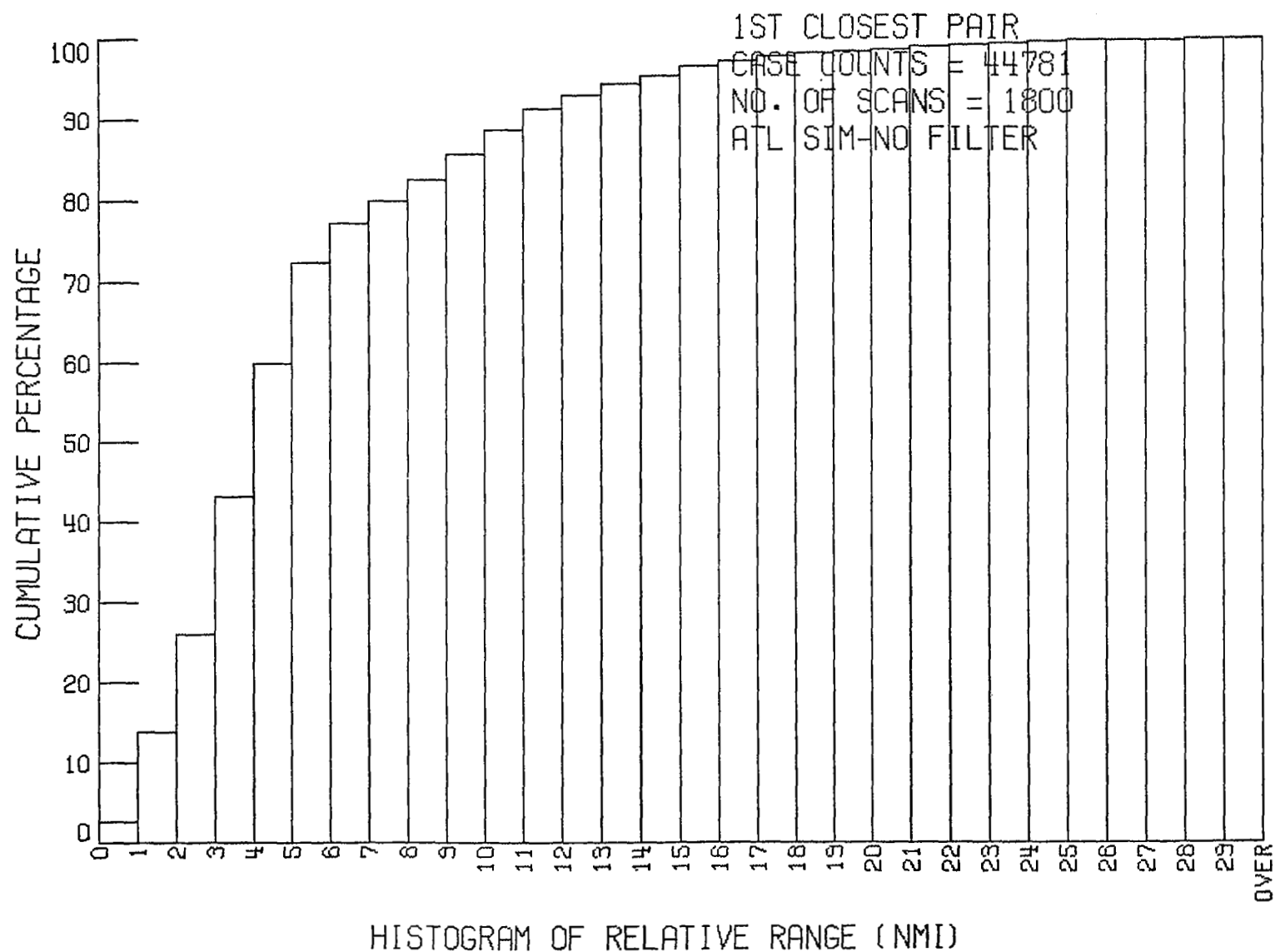
Figure 5.2. Histogram plot for conditions shown above (no filtering)

5TH CLOSEST PAIR
CASE COUNTS = 44781
NO. OF SCANS = 1800

HISTOGRAM OF RELATIVE RANGE (NMI)
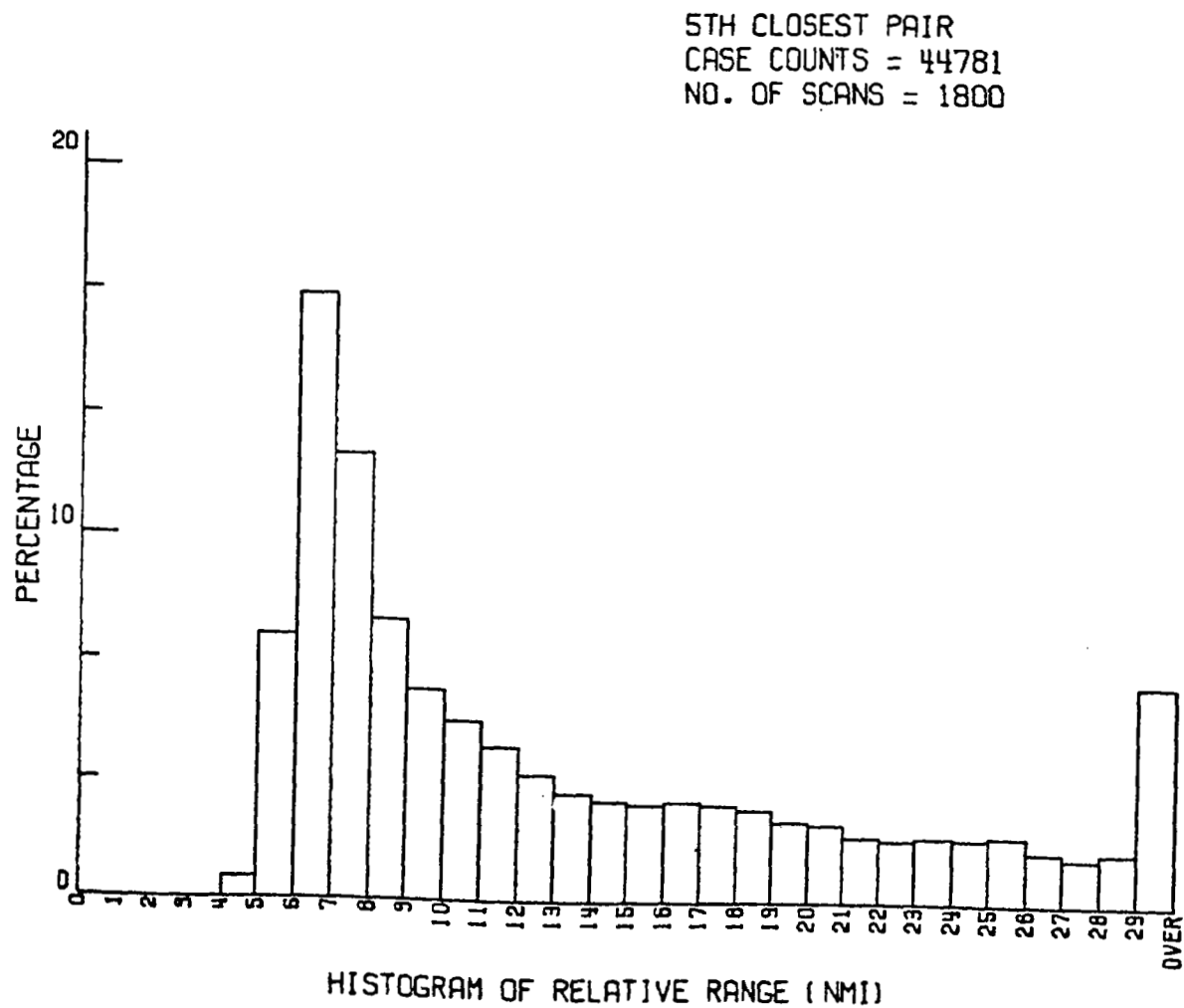
Figure 5.3. Histogram plot for conditions shown above (no filtering).
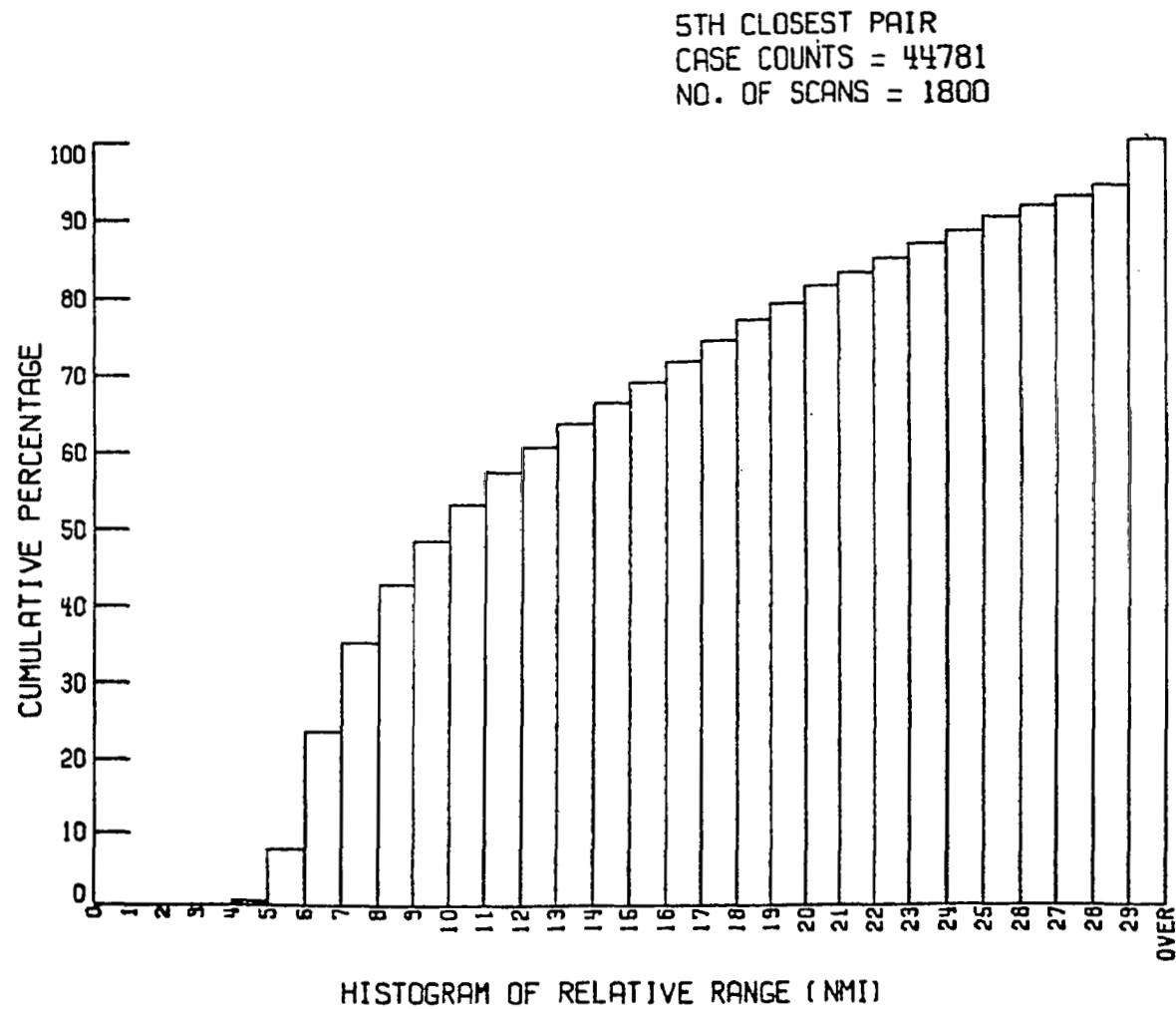
Figure 5.4. Histogram plot for conditions shown above (no filtering).

Figure5.5 Average percent of flying time that a randomly selected aircraft will have
N other aircraft simultaneously displayed within a range value given along
the horizontal axis. No discrimination is used.

Figure 5.6 Average percent of flying time that a randomly selected aircraft will have N other aircraft displayed simultaneously within a range value along the horizontal axis. Altitude discrimination of + 1,000 feet.

Figure 5.7 Average percent of flying time that a randomly selected aircraft will have N other
aircraft simultaneously displayed within a range value given along the horizontal
axis.   Altitude discrimination of $\pm$ 2,000 feet.

Figure 5.8. Average percentage of flying time in the terminal area vs. number
of aircraft observed within a range of 5 n. mi. Curves are given
for all altitudes, ±1000 ft. altitude, and ±2000 ft. altitude.

Figure 5.9.   Average percentage of flying time in the terminal area vs. number
              of aircraft observed within a range of 8 n. mi. Curves are given
              for all altitudes, +1000 ft. altitude, and +2000 ft. altitude.

Figure 5.10. Average percentage of flying time in the terminal area vs. number of aircraft observed within a range of 10 n. mi. Curves are given for all altitudes, +1000 ft. altitude, and +2000 ft. altitude.

Figure 5.11. Average percentage of flying time in the terminal area vs. number of aircraft observed within a range of 12 n. mi. Curves are given for all altitudes, +1000 ft. altitude, and +2000 ft. altitude.

Figure 5.12. Average percentage of flying time in the terminal area vs. number of aircraft observed within a range of 15 n. mi. Curves are given for all altitudes, $\pm$1000 ft. altitude, and $\pm$2000 ft. altitude.

Figure 5.13. Average percentage of flying time in the terminal area vs. number of aircraft observed within a range of 20 n. mi. Curves are given for all altitudes, ±1000 ft. altitude, and ±2000 ft. altitude.

Figure 5.14. Average percentage of flying time in the terminal area vs. number of aircraft observed within a range of 25 n. mi. Curves are given for all altitudes, ±1000 ft. altitude, and ±2000 ft. altitude.
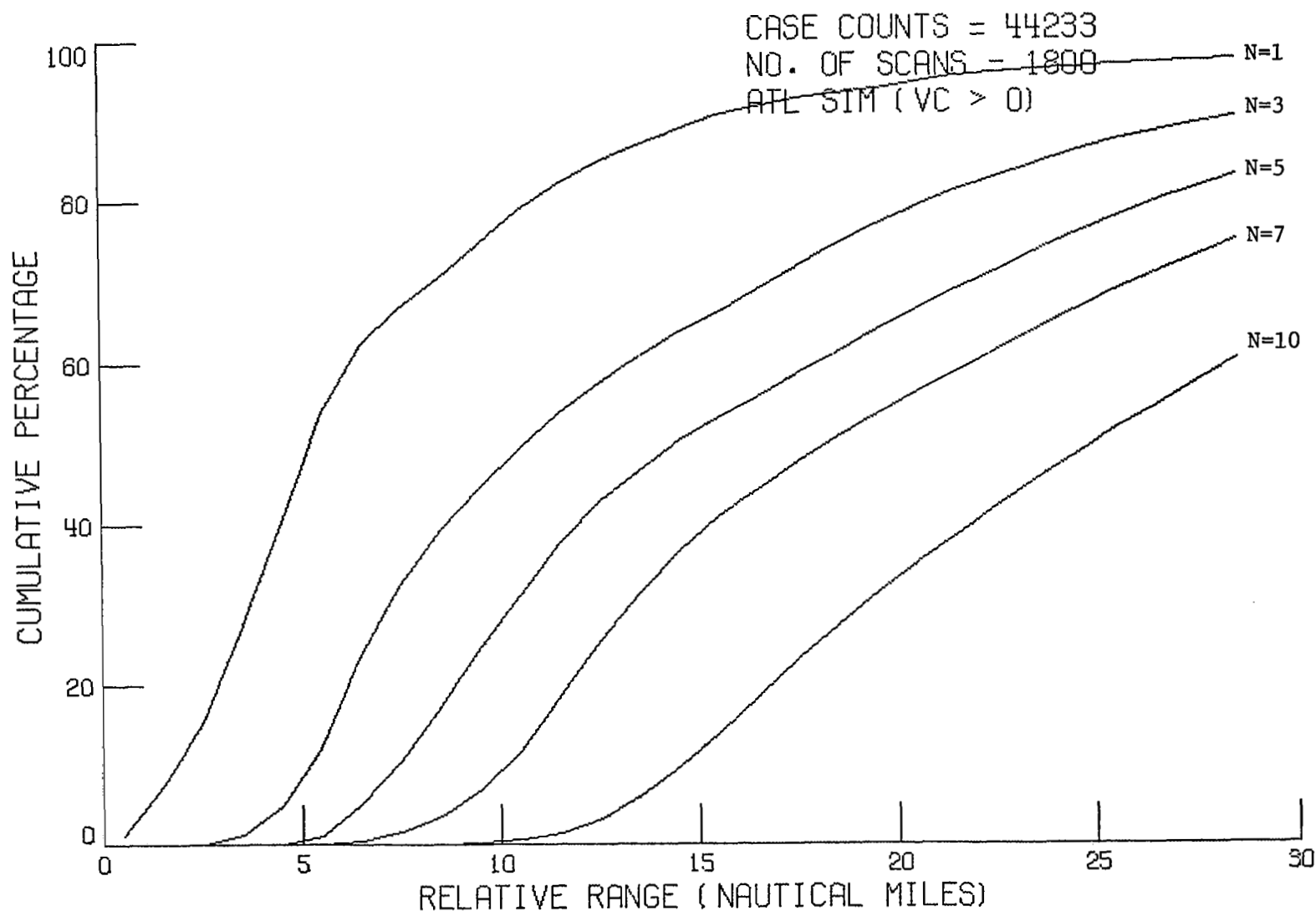
Figure 5.15 Average percent of flying time that a randomly selected aircraft will have N other aircraft simultaneously displayed within a range value given along the horizontal axis. Closing velocity discrimination ($V_c > 0$).
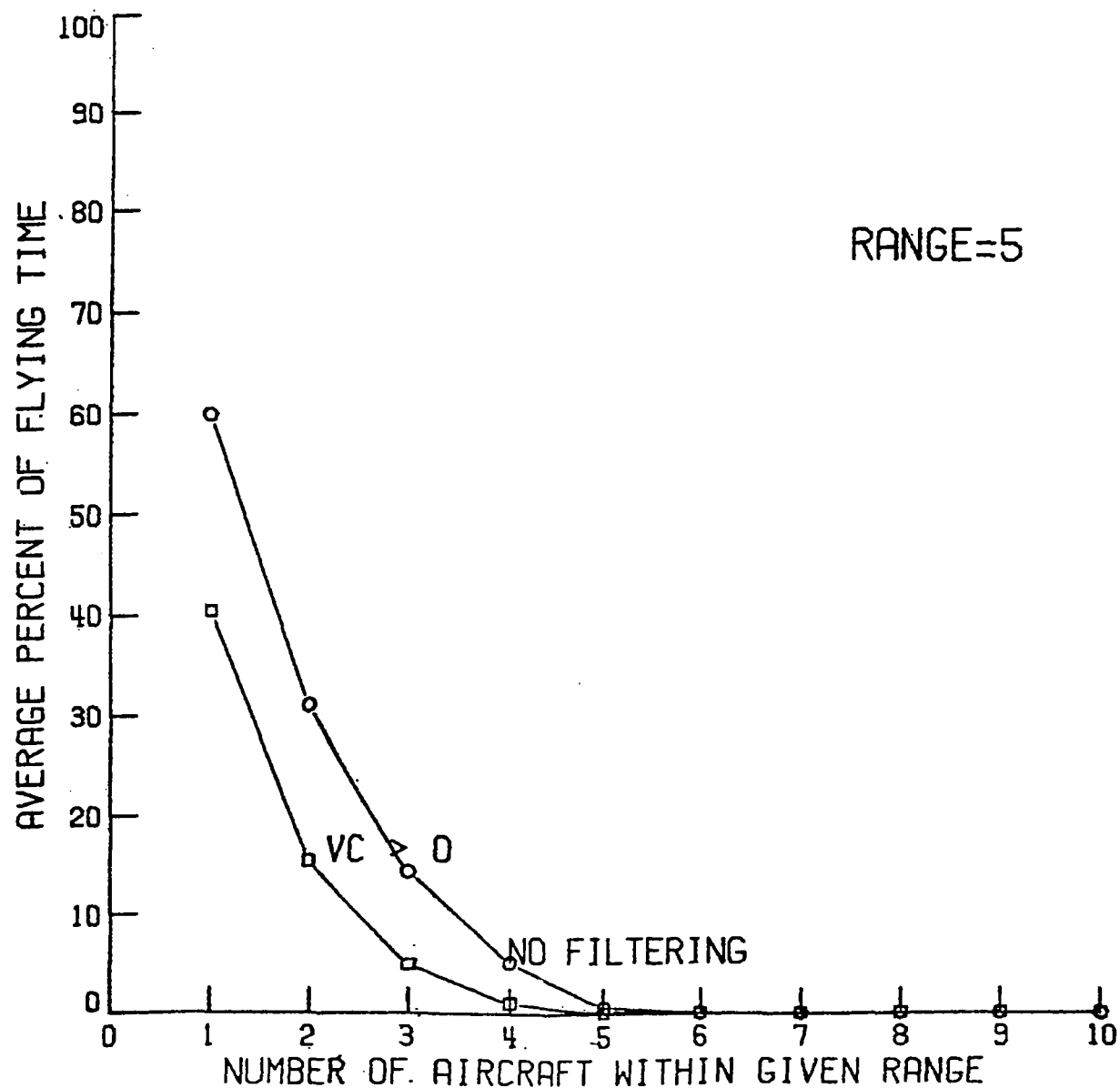
Figure 5.16. Average percent of flying time that a given number of aircraft will be found within a range of 5 nautical miles with no filtering and with closing velocity filtering.
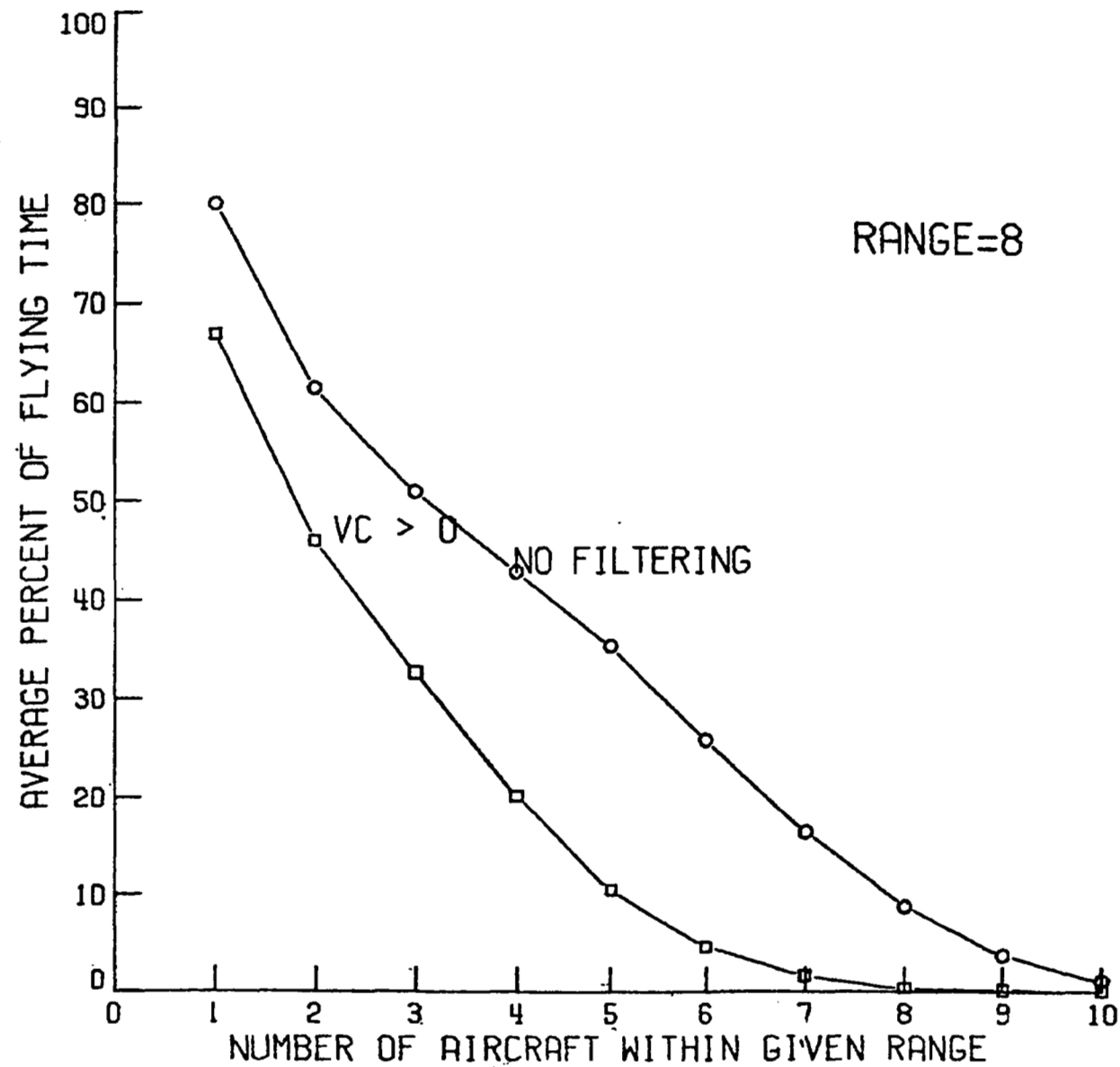
Figure 5.17. Average percent of flying time that a given number of aircraft will be found within a range of 8 nautical miles with no filtering and with closing velocity filtering.
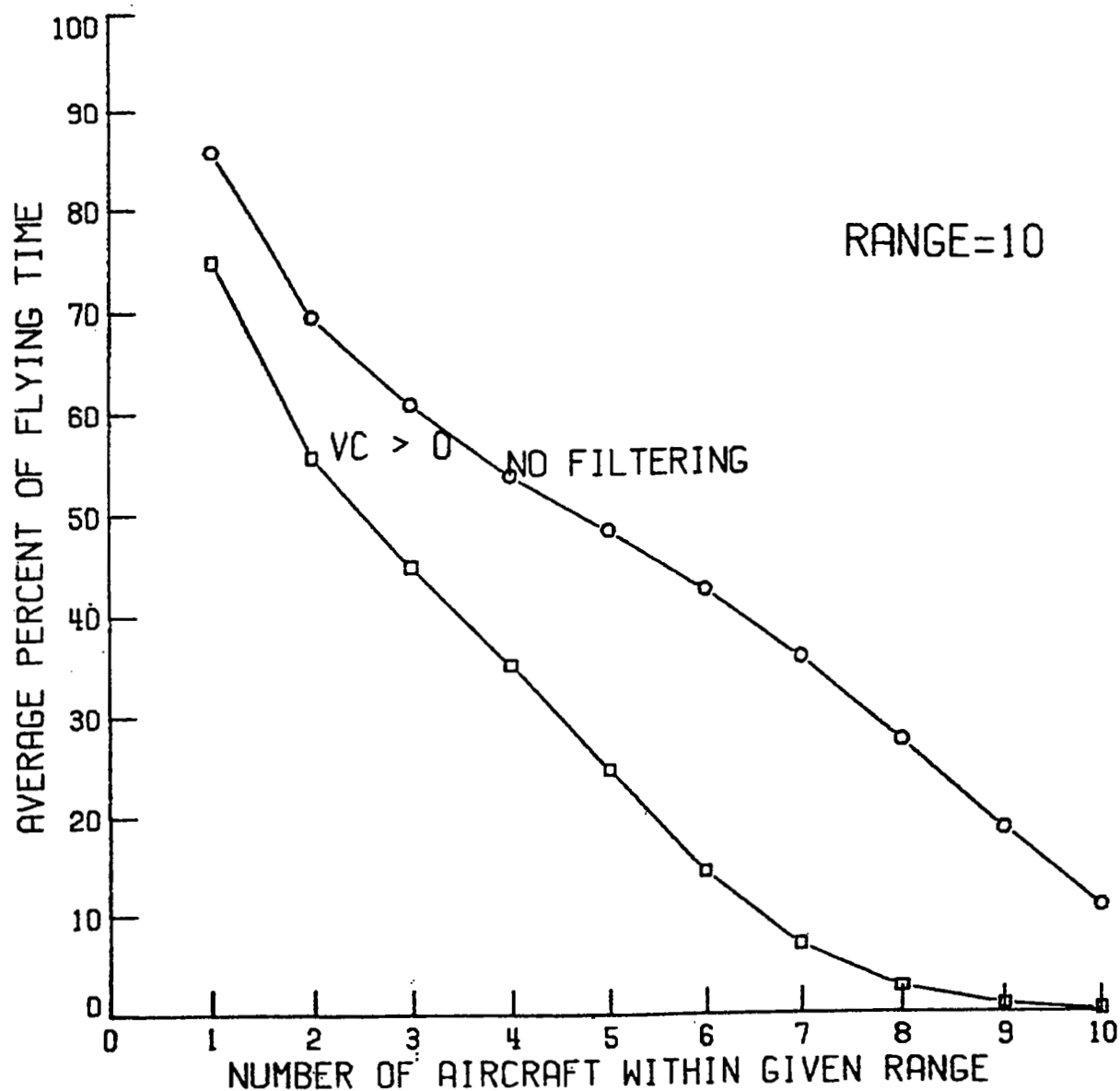
Figure 5.18. Average percent of flying time that a given number of aircraft will be found within a range of 10 nautical miles with no filtering and with closing velocity filtering.
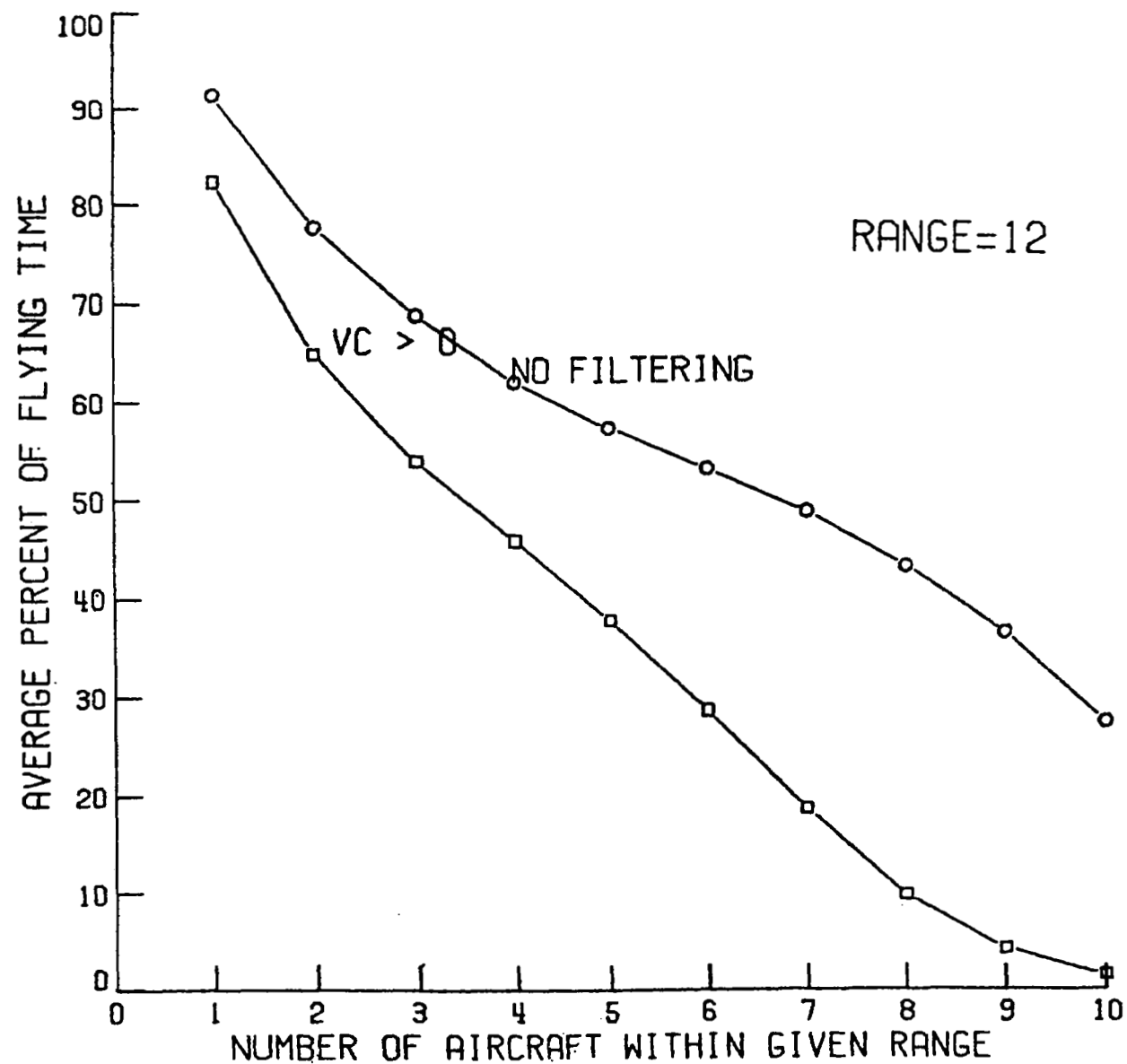
Figure 5.19. Average percent of flying time that a given number of aircraft will be found within a range of 12 nautical miles with no filtering and with closing velocity filtering.
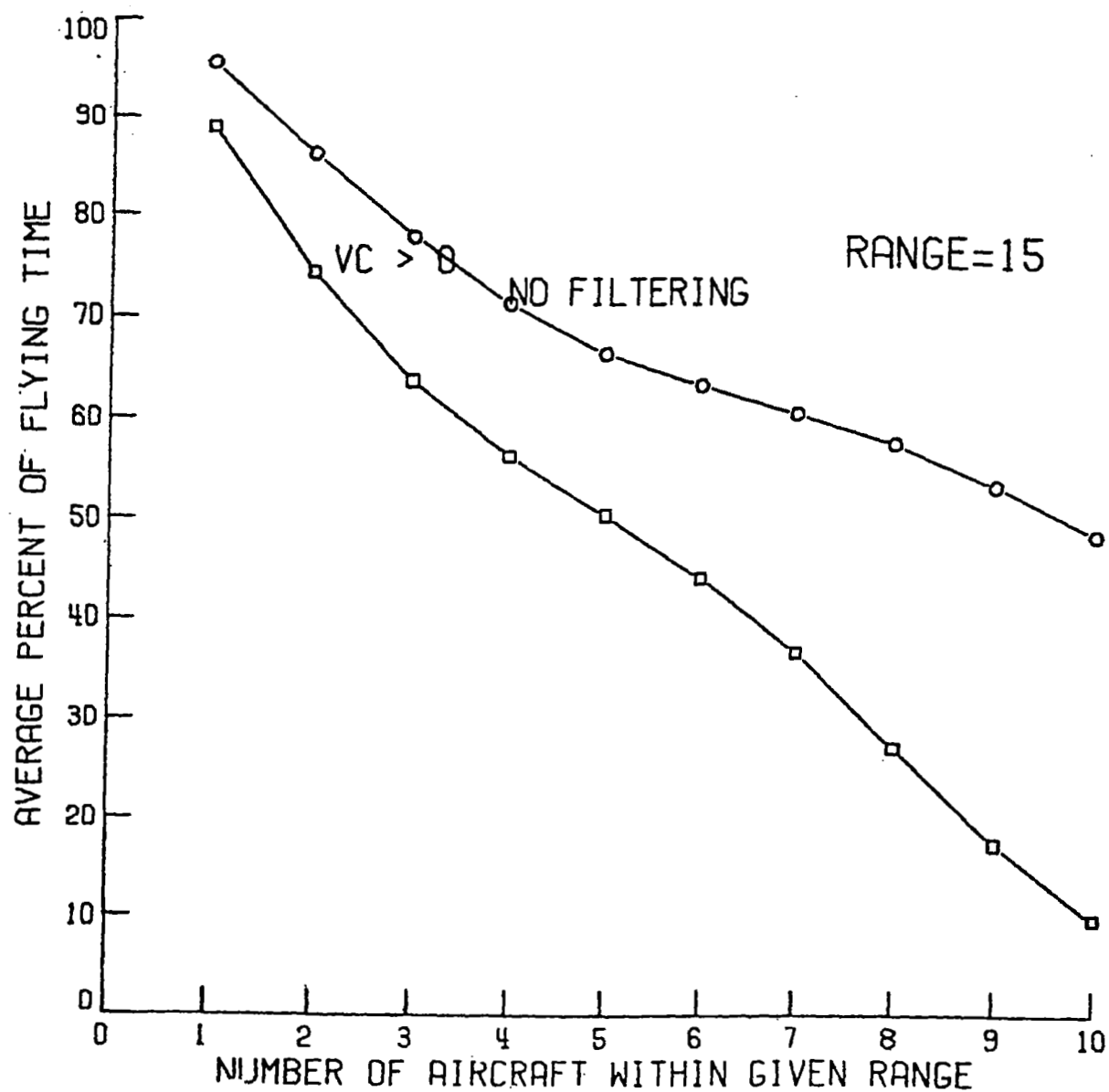
Figure 5.20. Average percent of flying time that a given number of aircraft will be found within a range of 15 nautical miles with no filtering and with closing velocity filtering.
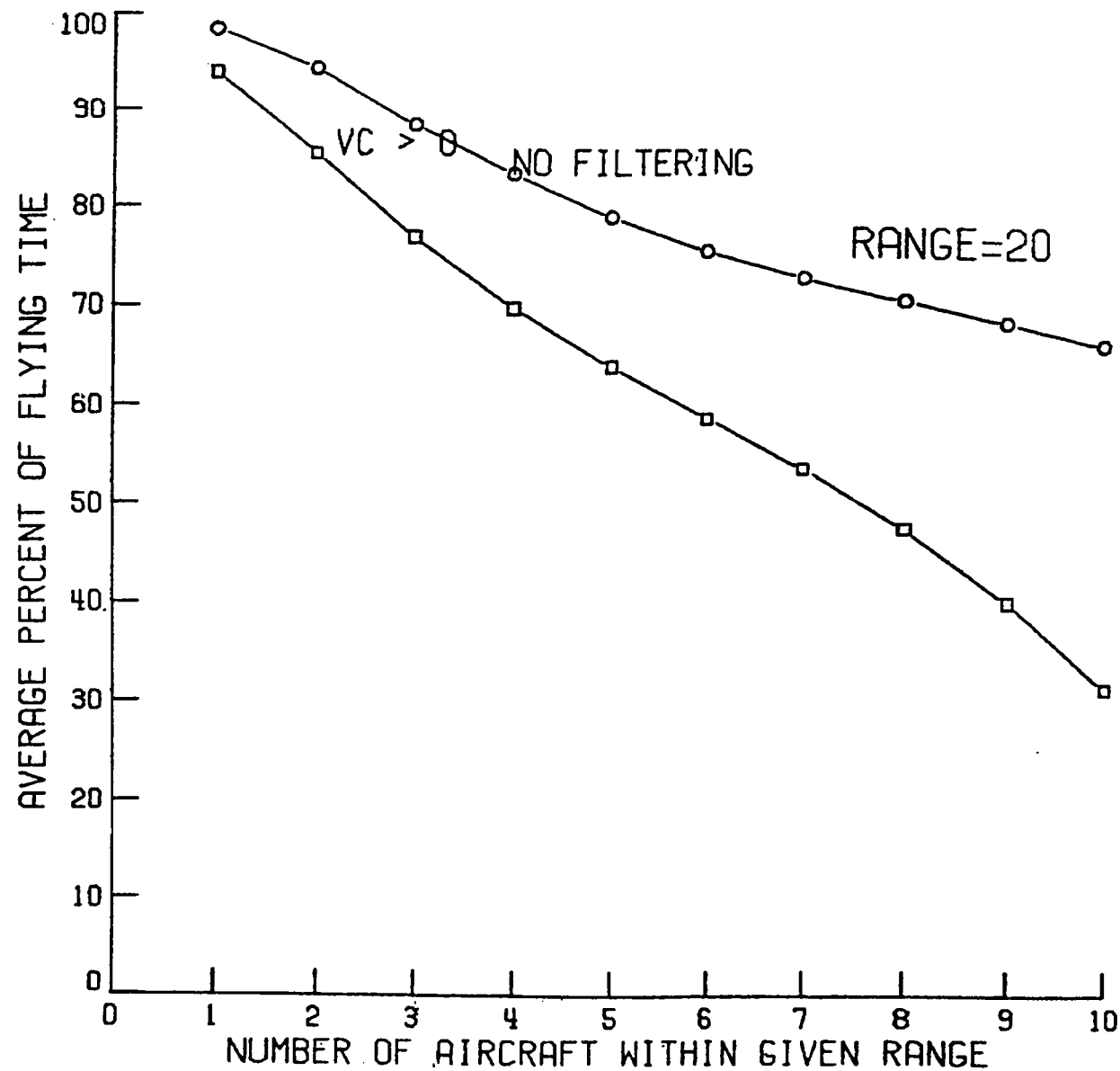
Figure 5.21.   Average percent of flying time that a given number of aircraft will be found within a
range of 20 nautical miles with no filtering and with closing velocity filtering.
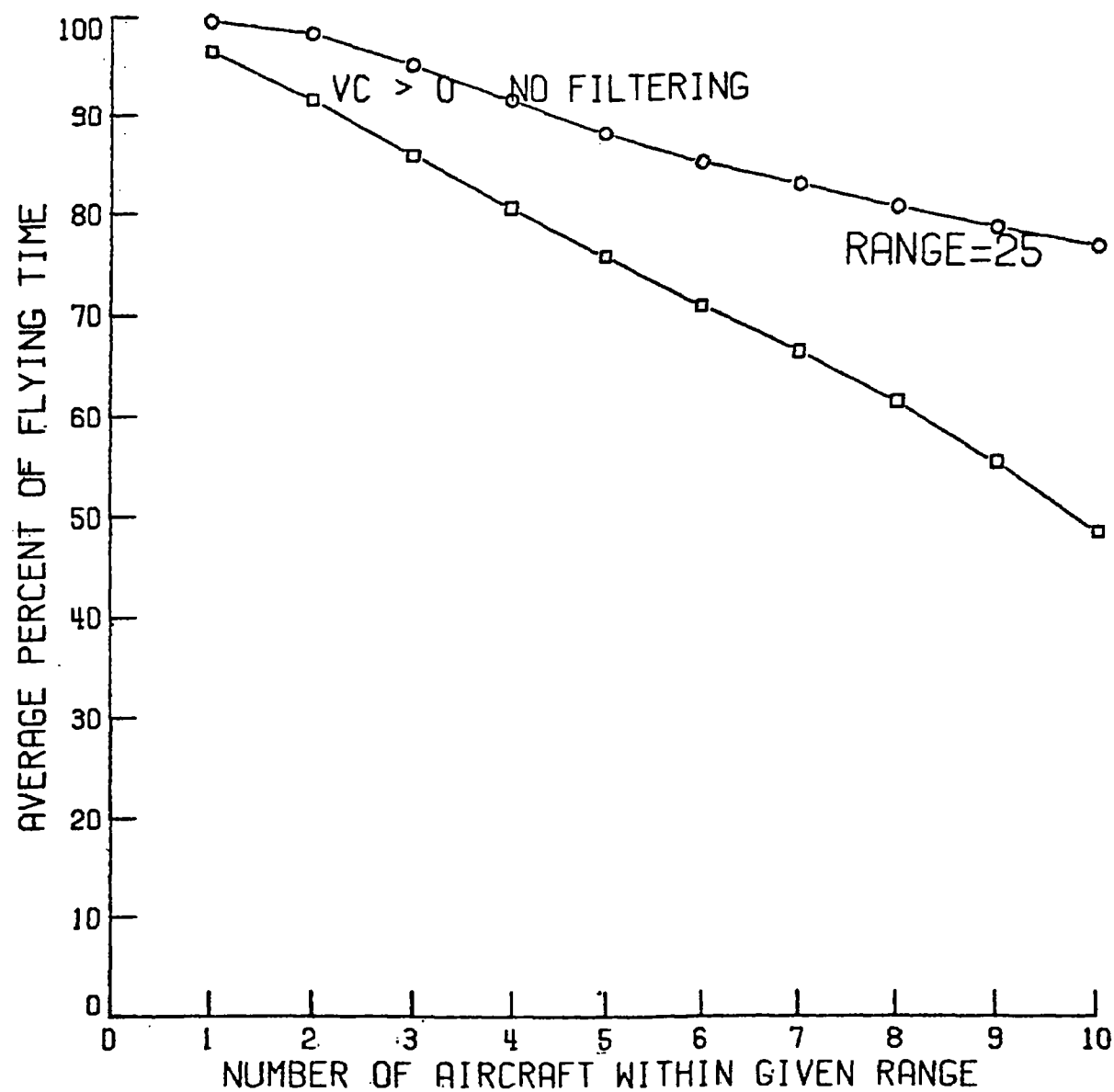
Figure 5.22. Average percent of flying time that a given number of aircraft will be found within a range of 25 nautical miles with no filtering and with closing velocity filtering.
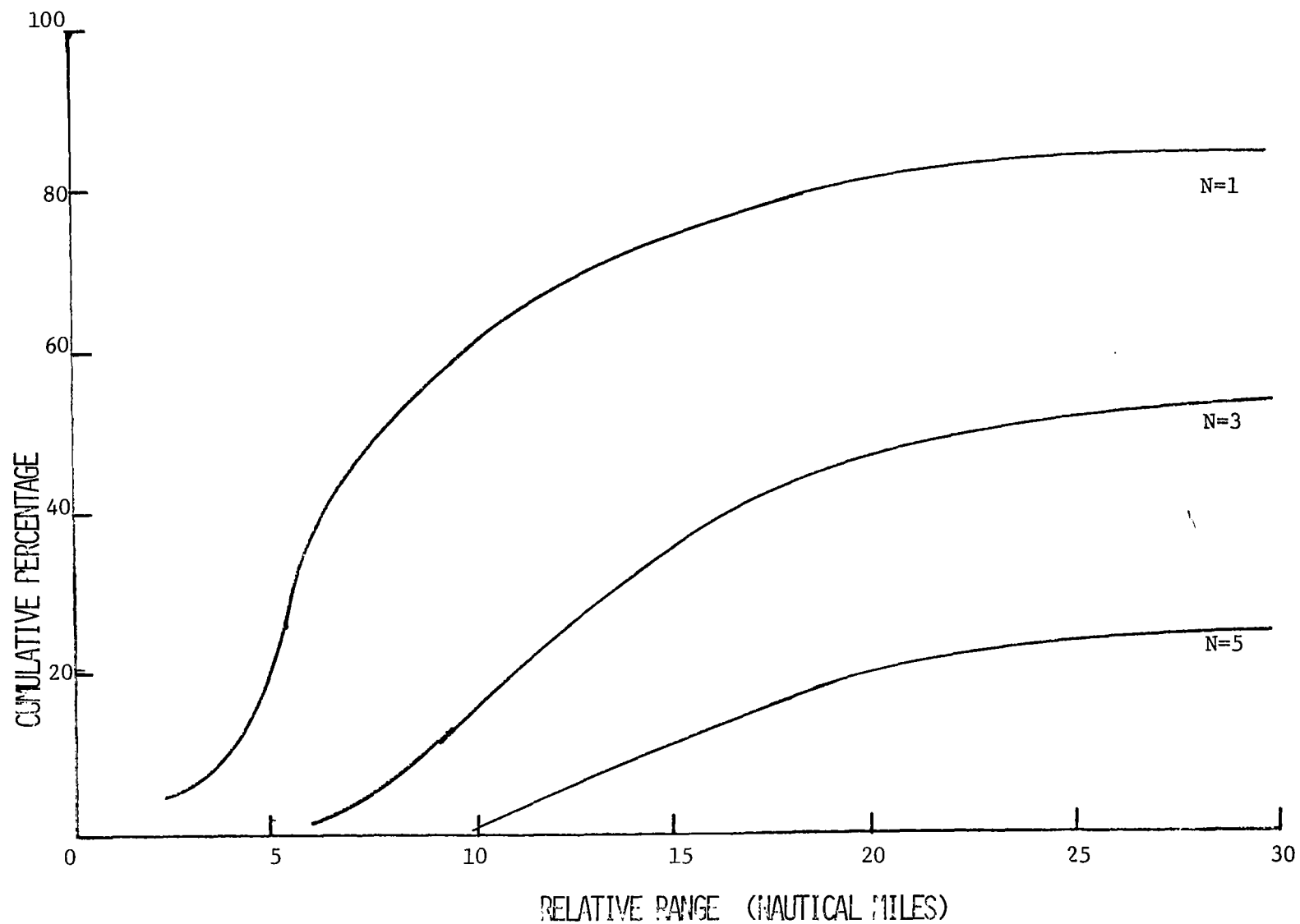
Figure 5.23. Average percent of flying time that a randomly selected aircraft will have N other aircraft simultaneously displayed within a range value given along the horizontal axis for τ < 240 secs. discrimination.

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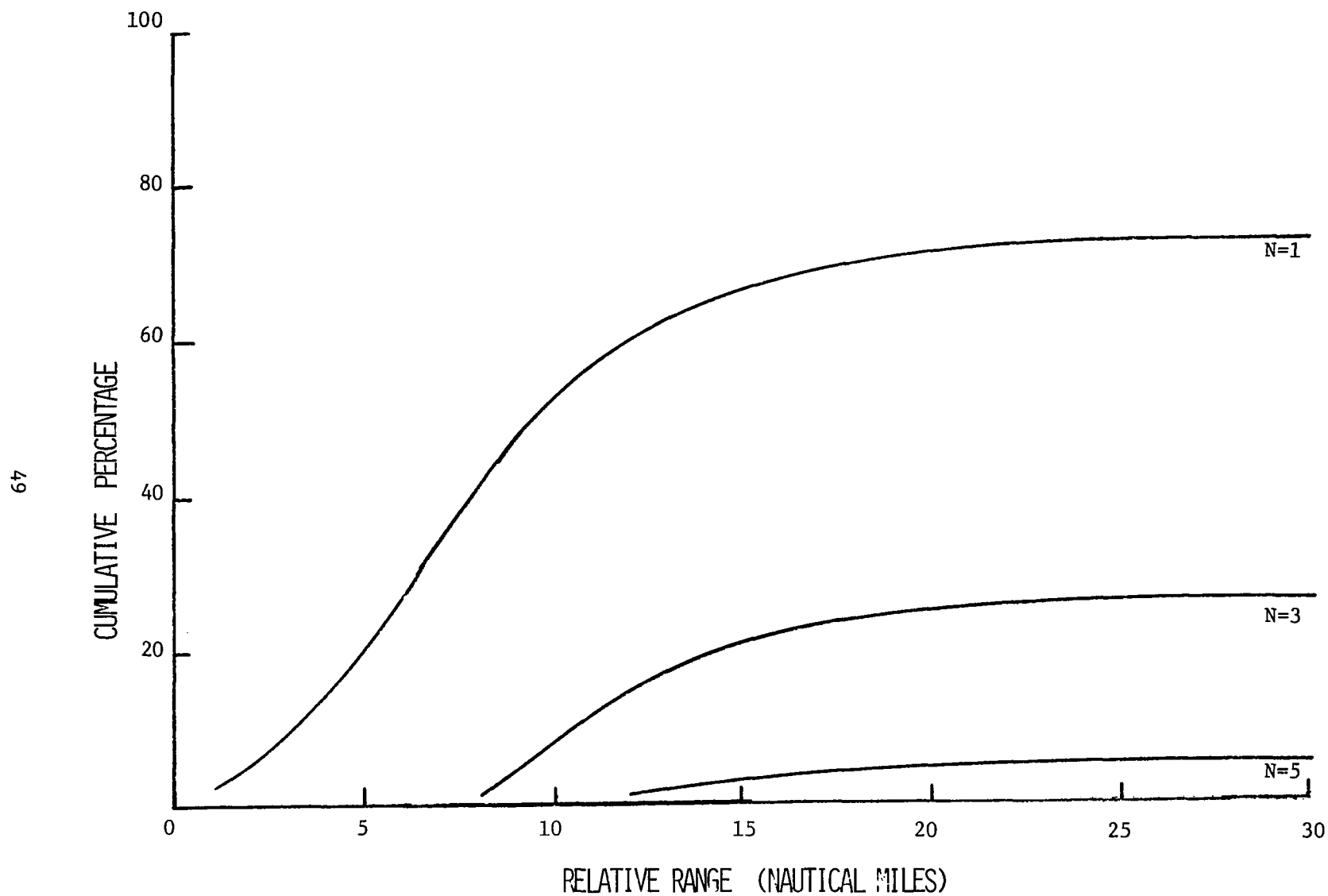
Figure 5.24.   Average percent of flying time that a randomly selected aircraft will have N other aircraft simultaneously displayed within a range value given along the horizontal axis for τ < 180 secs. discrimination.
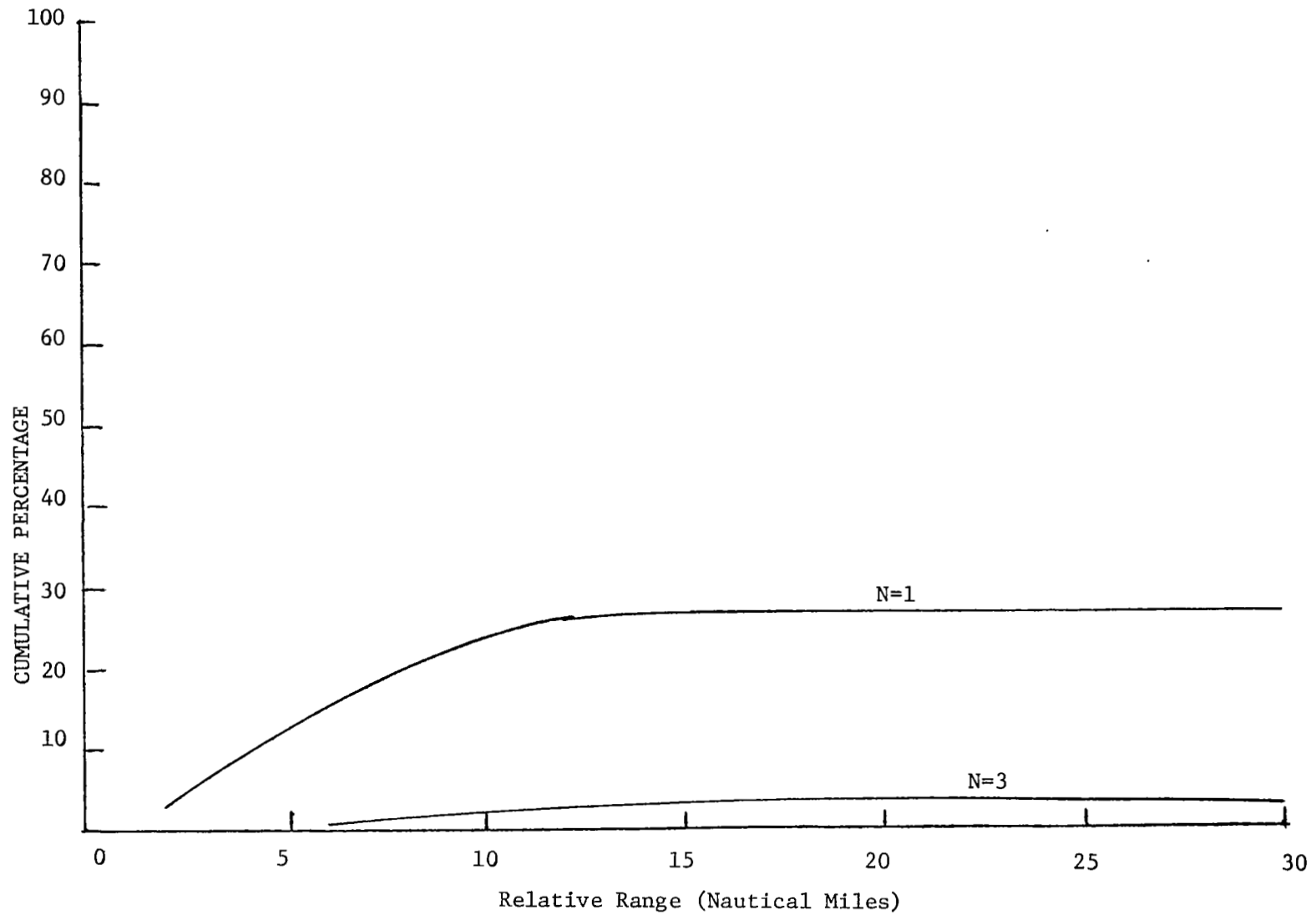
Figure 5.25. Average percent of flying time that a randomly selected aircraft will have N
other aircraft simultaneously displayed within a range value given along the
horizontal axis for $\tau < 120$ secs. discrimination
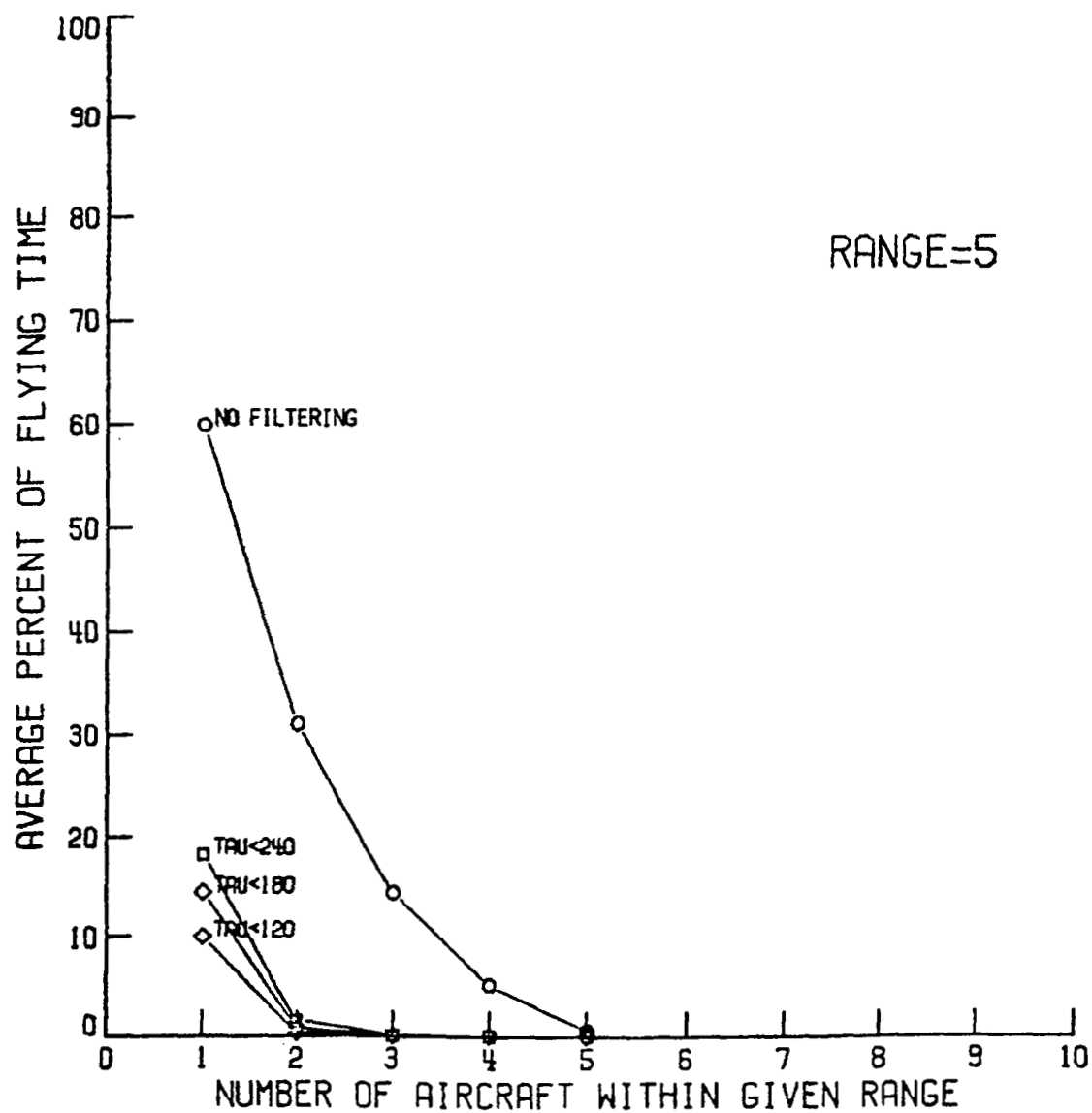
Figure 5.26. Average percent of flying time that a given number of aircraft will be found within a range of 5 nautical miles with no filtering and with Tau filtering.
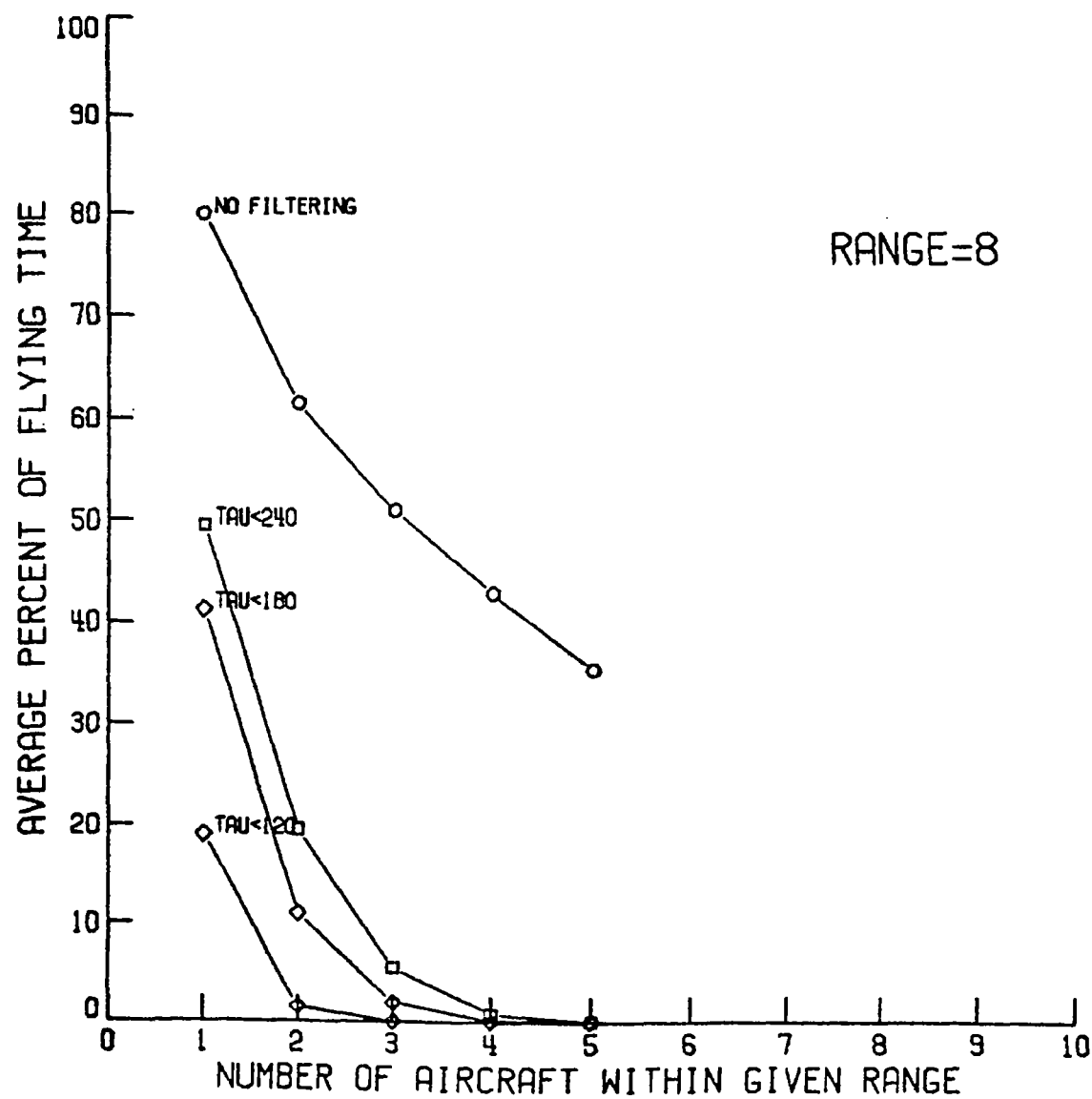
Figure 5.27. Average percent of flying time that a given number of aircraft will be found within a range of 8 nautical miles with no filtering and with Tau filtering.
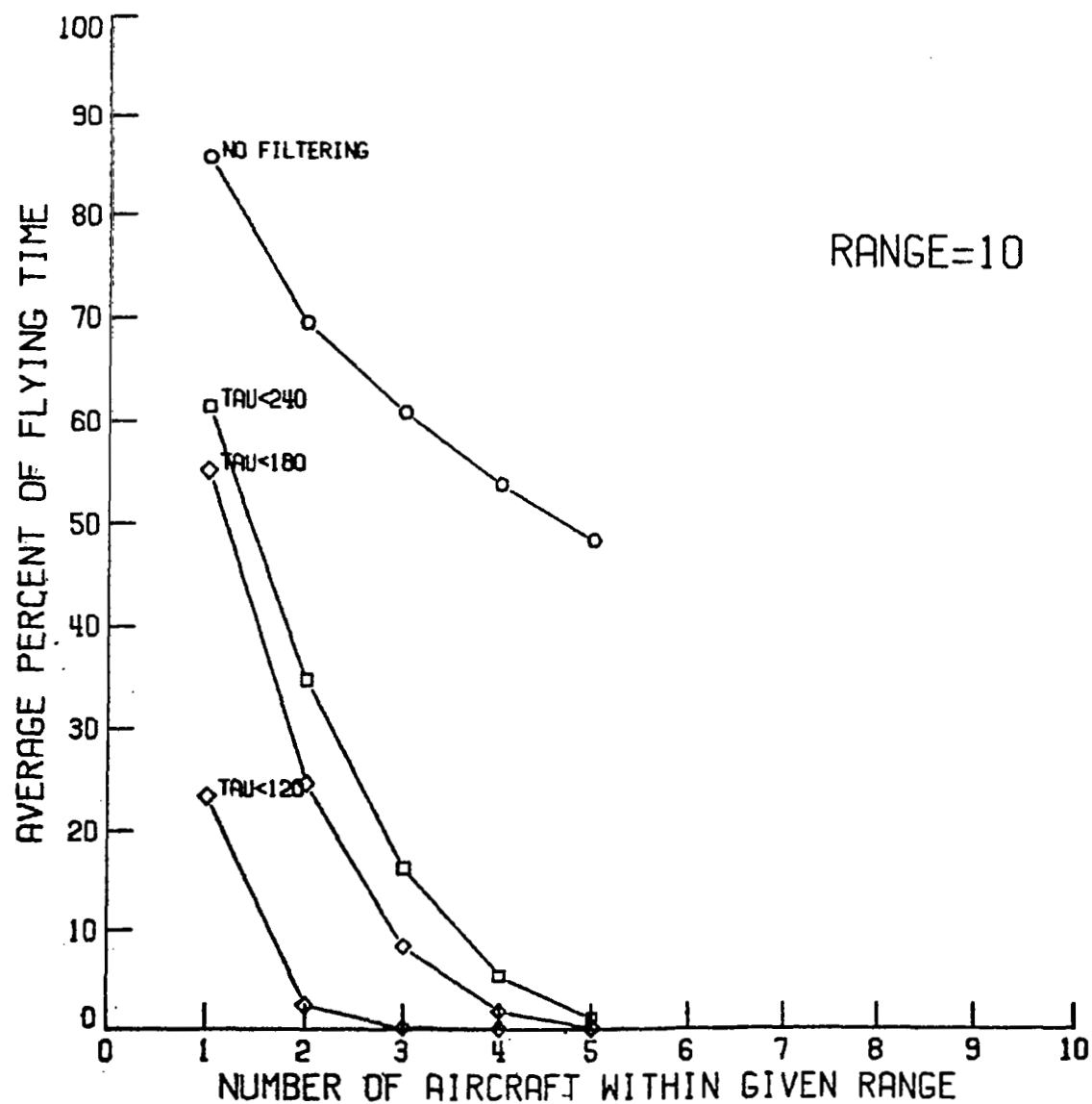
Figure 5.28. Average percent of flying time that a given number of aircraft will be found within a range of 10 nautical miles with no filtering and with Tau filtering.
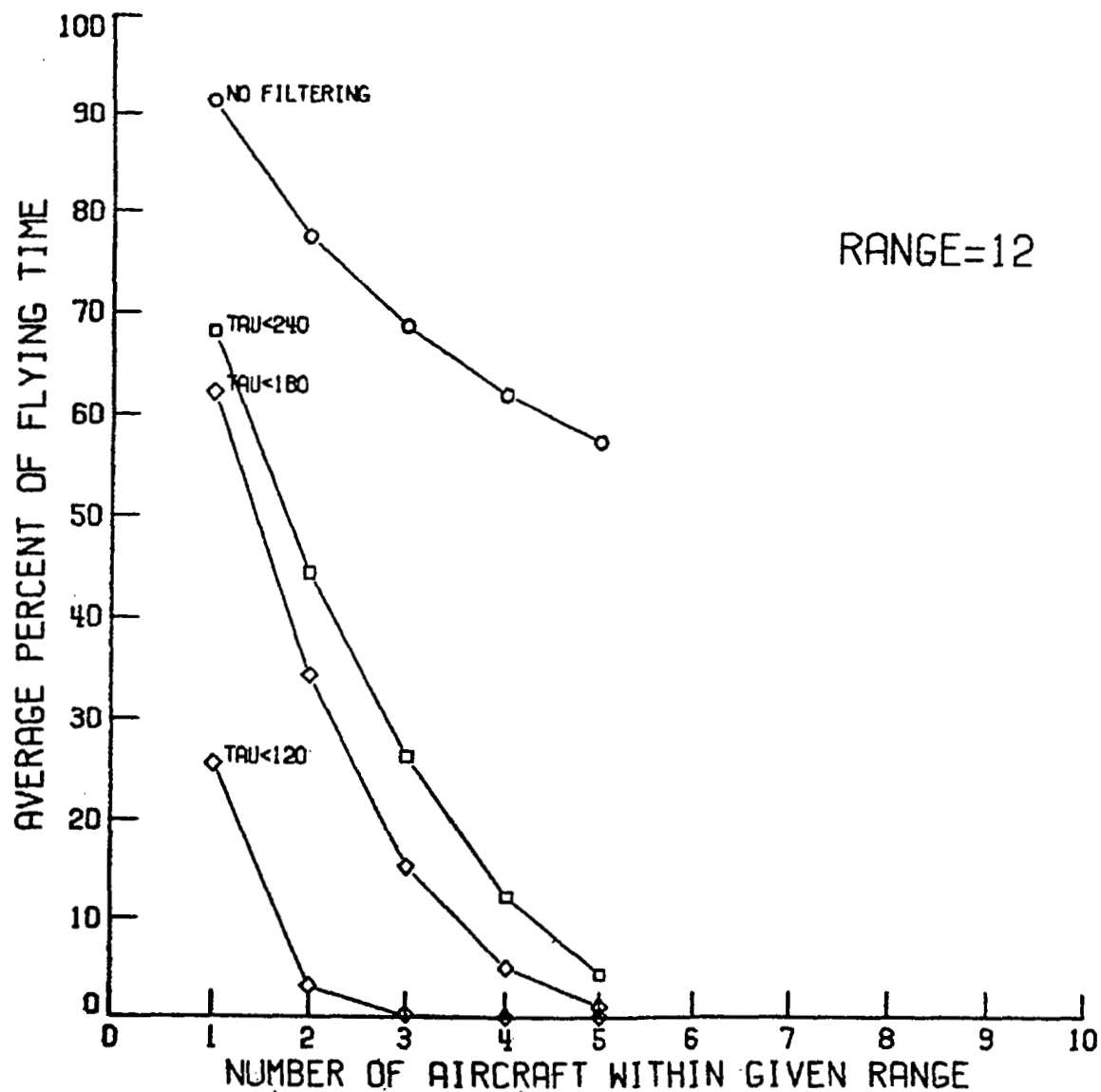
Figure 5.29. Average percent of flying time that a given number of aircraft will be found within a range of 12 nautical miles with no filtering and with Tau filtering.
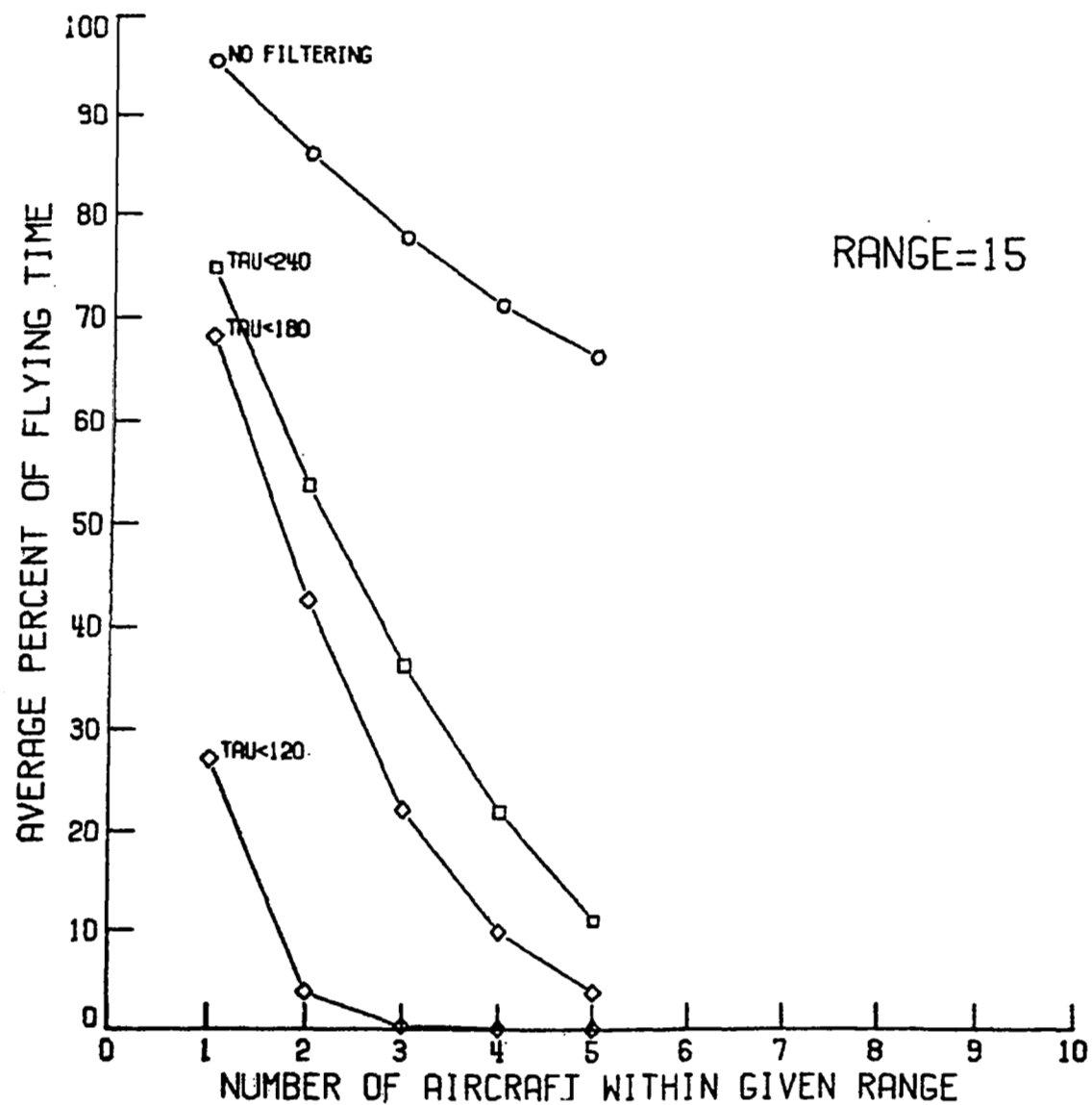
Figure 5.30. Average percent of flying time that a given number of aircraft will be found within a range of 15 nautical miles with no filtering and with Tau filtering.
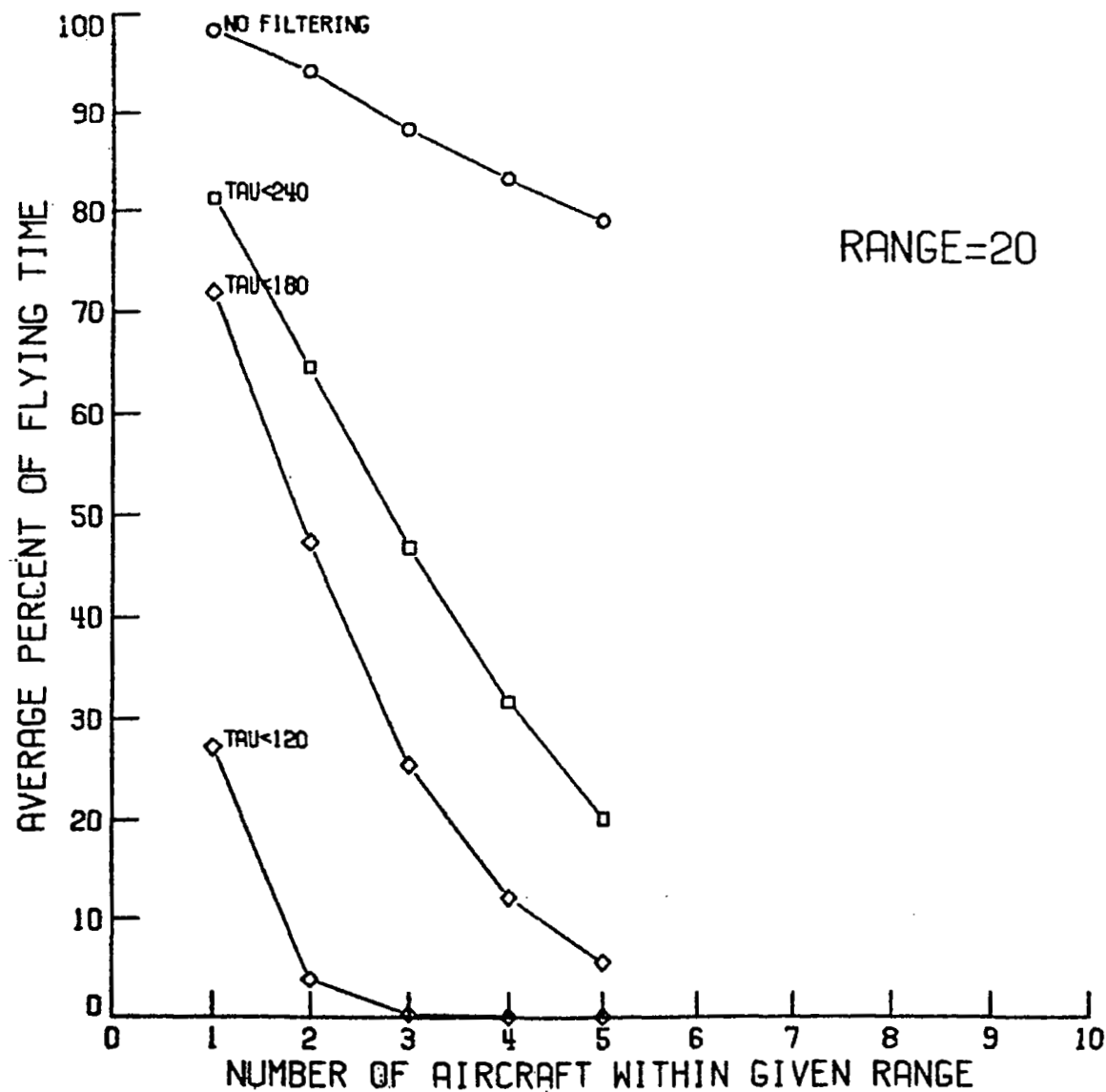
Figure 5.31. Average percent of flying time that a given number of aircraft will be found within a range of 20 nautical miles with no filtering and with Tau filtering.
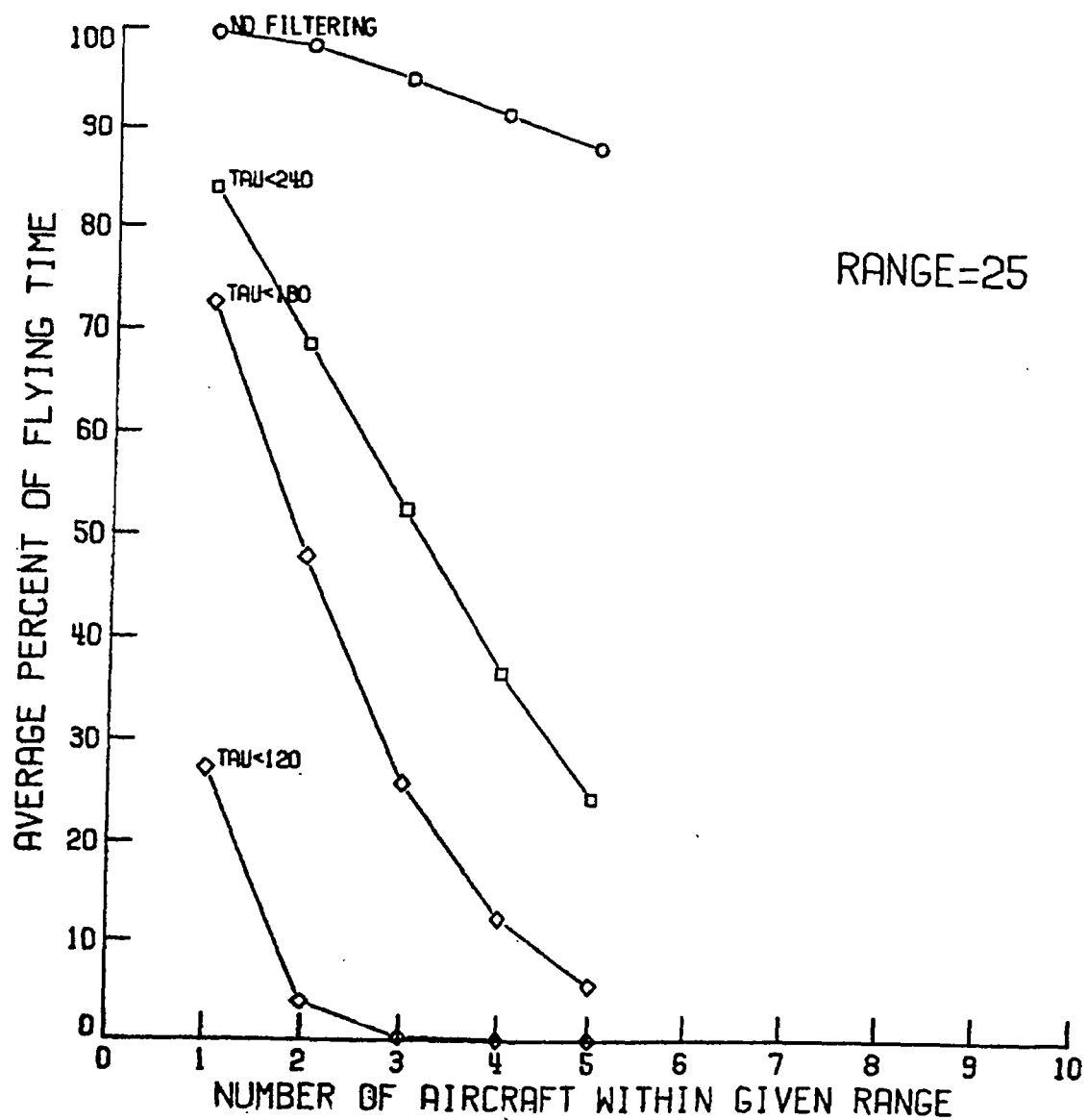
Figure 5.32. Average percent of flying time that a given number of aircraft will be found within a range of 25 nautical miles with no filtering and with Tau filtering.
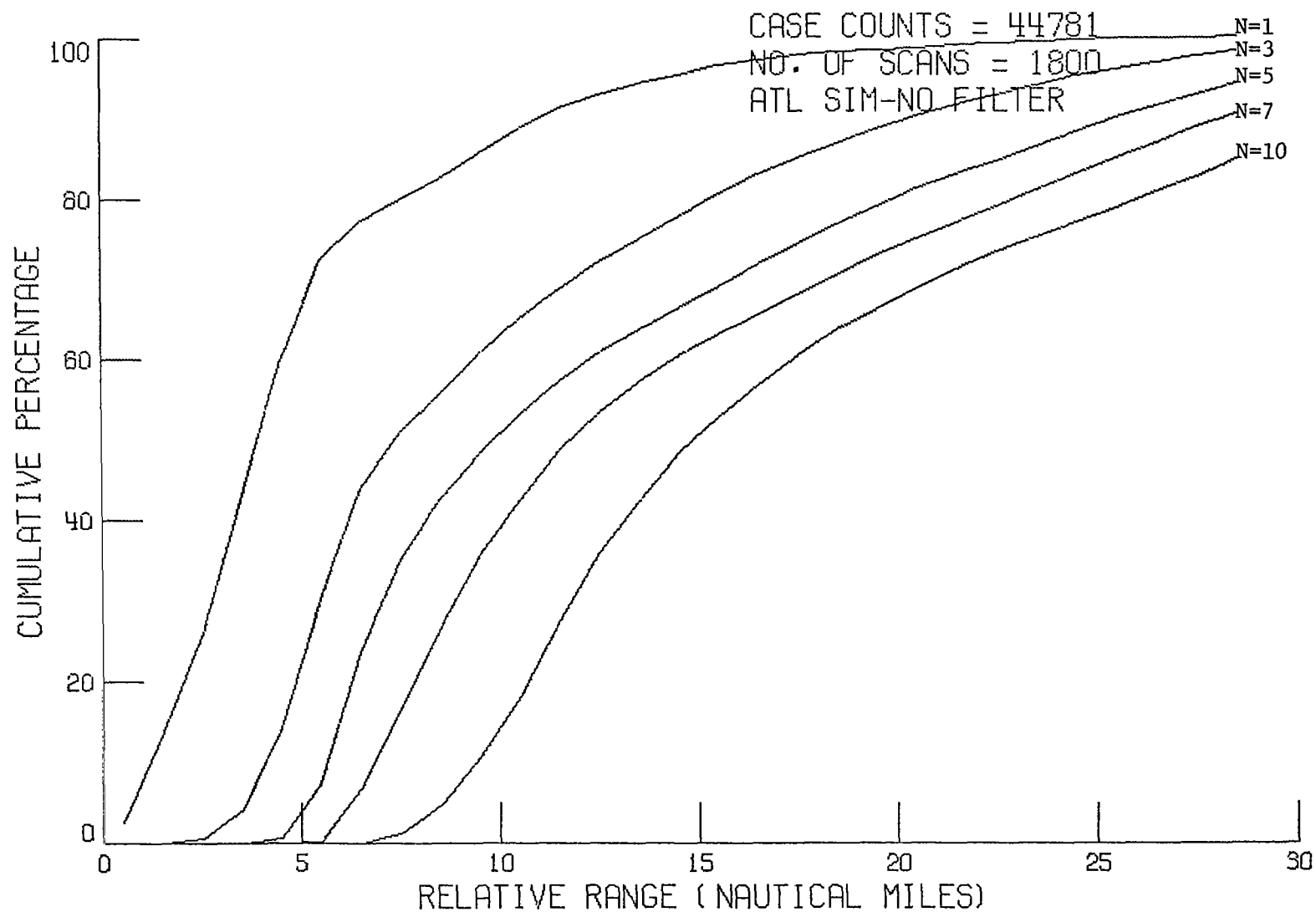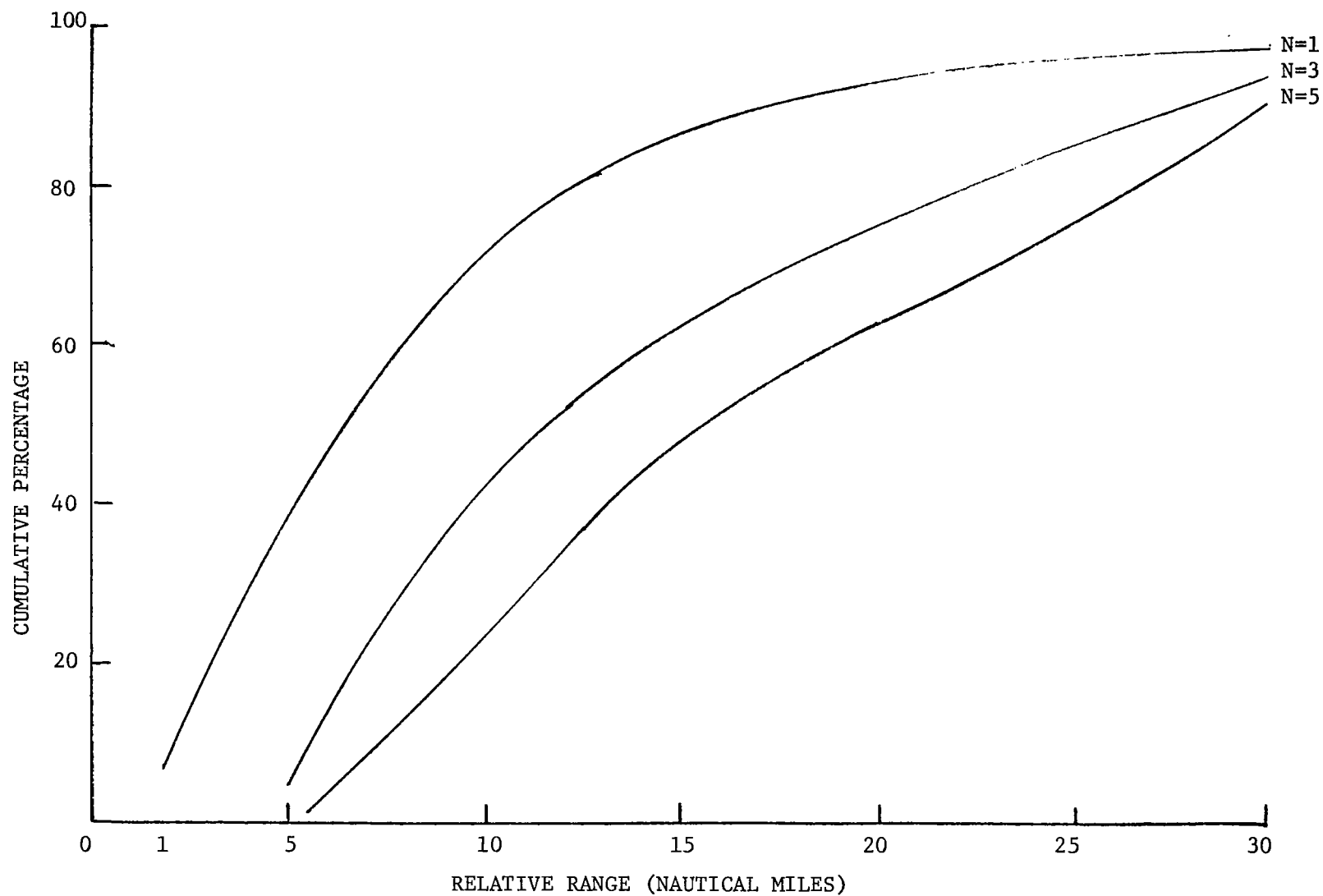
Figure 5.33. Average percent of flying time that a randomly selected aircraft will have N other aircraft simultaneously displayed within a range value given along the horizontal axis for $\tau_m < 180$ secs. discrimination.
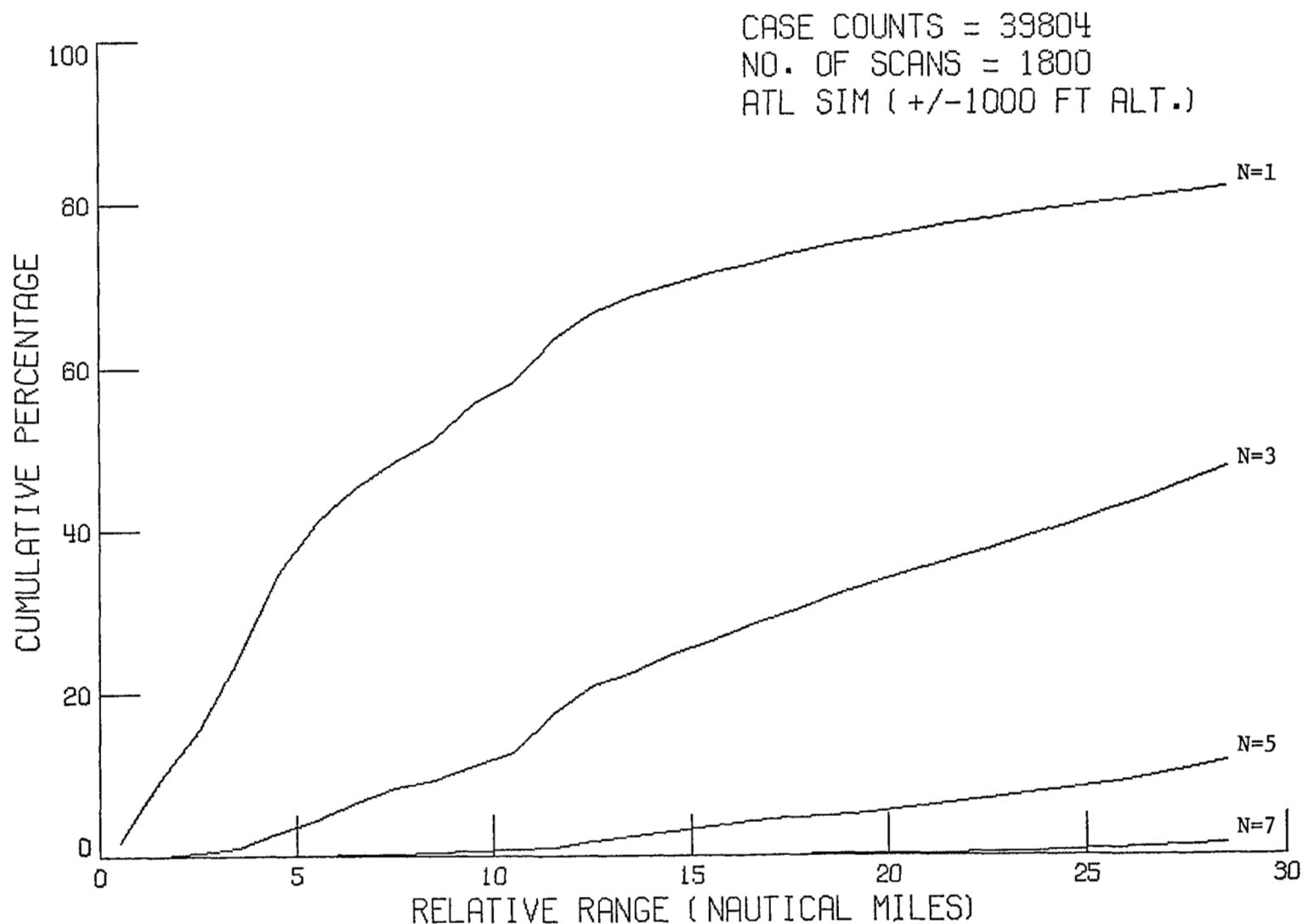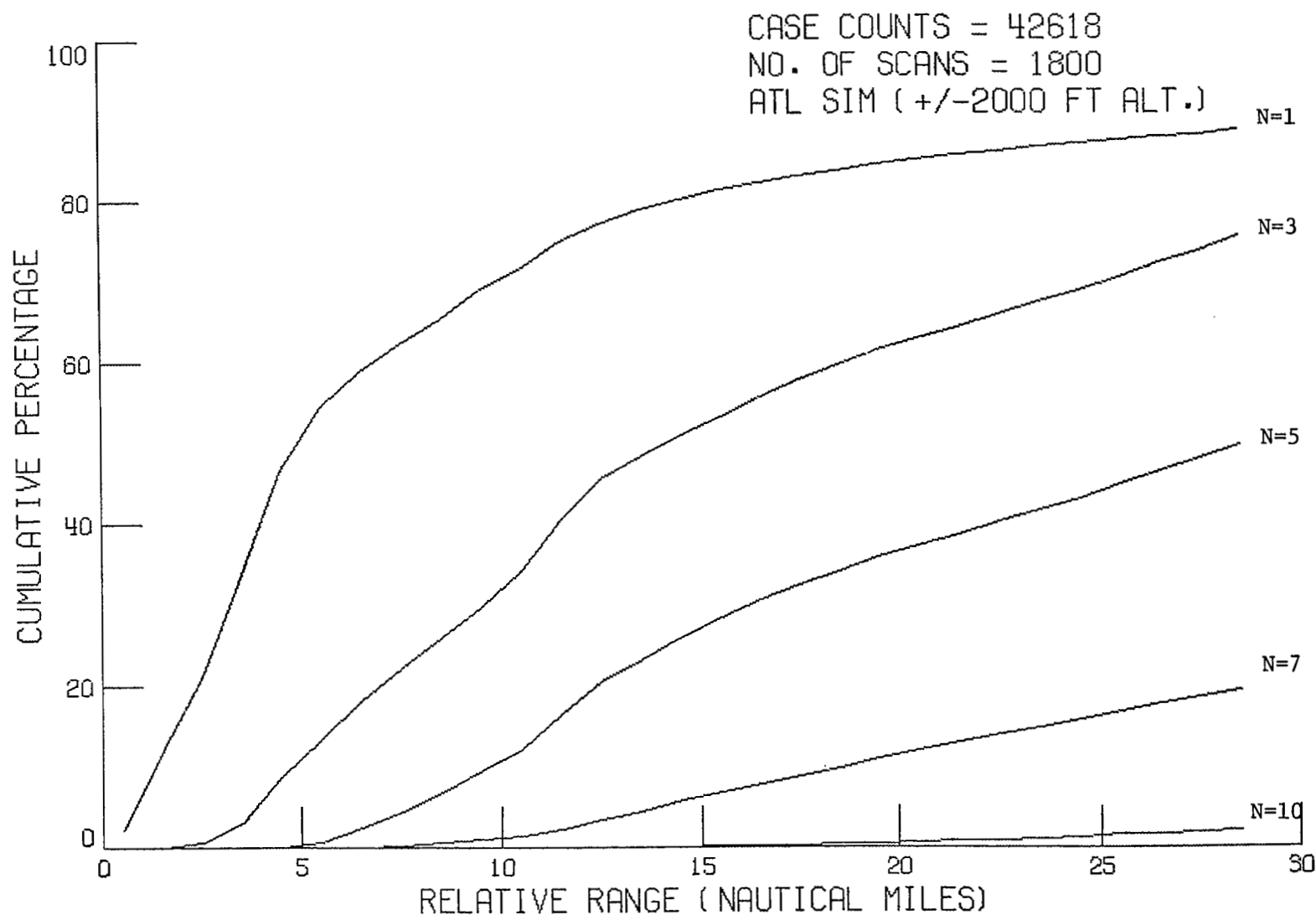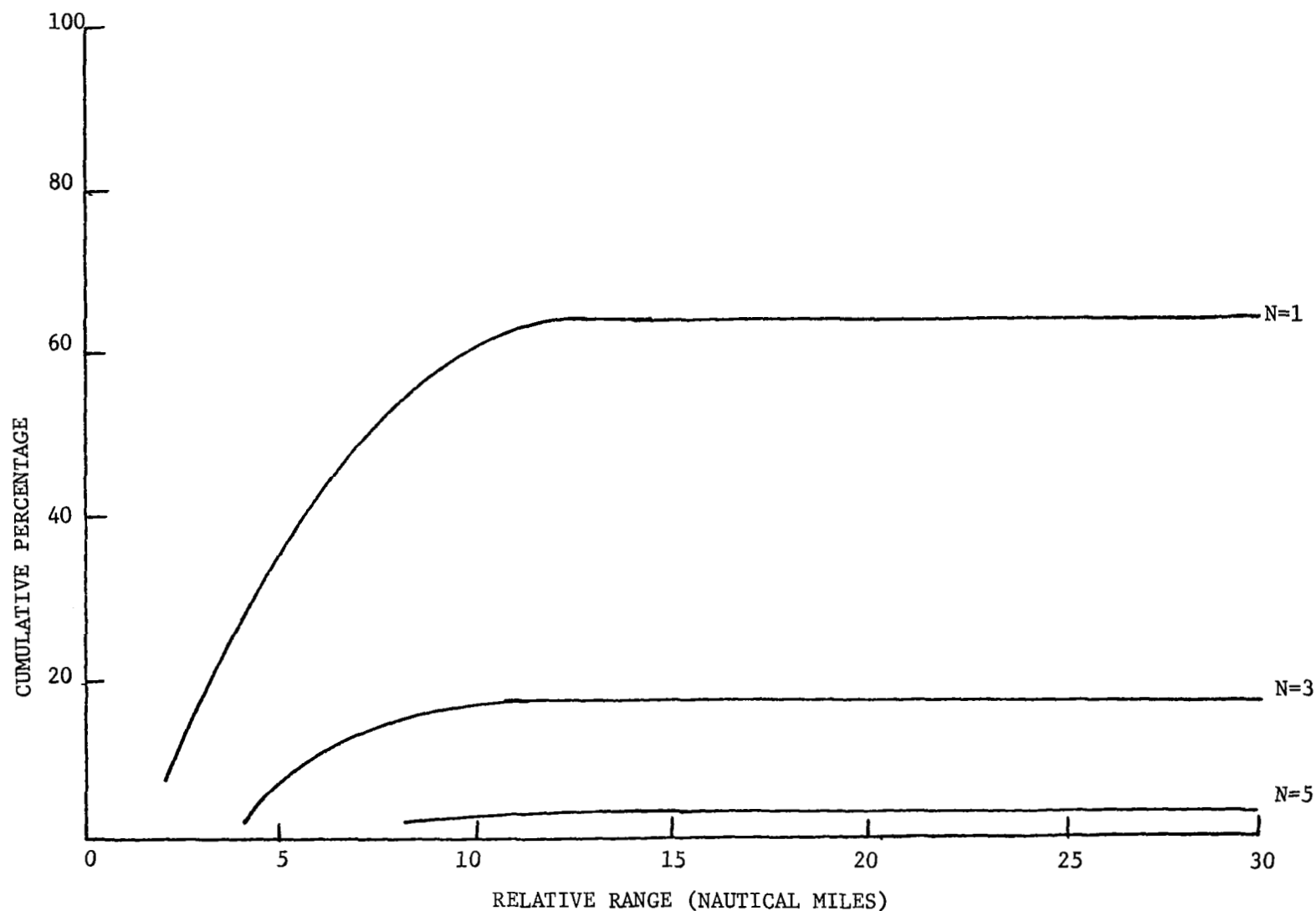
Figure 5.34. Average percent of flying time that a randomly selected aircraft will have N other aircraft simultaneously displayed within a range value given along the horizontal axis for $\tau_m < 60$ secs. discrimination.
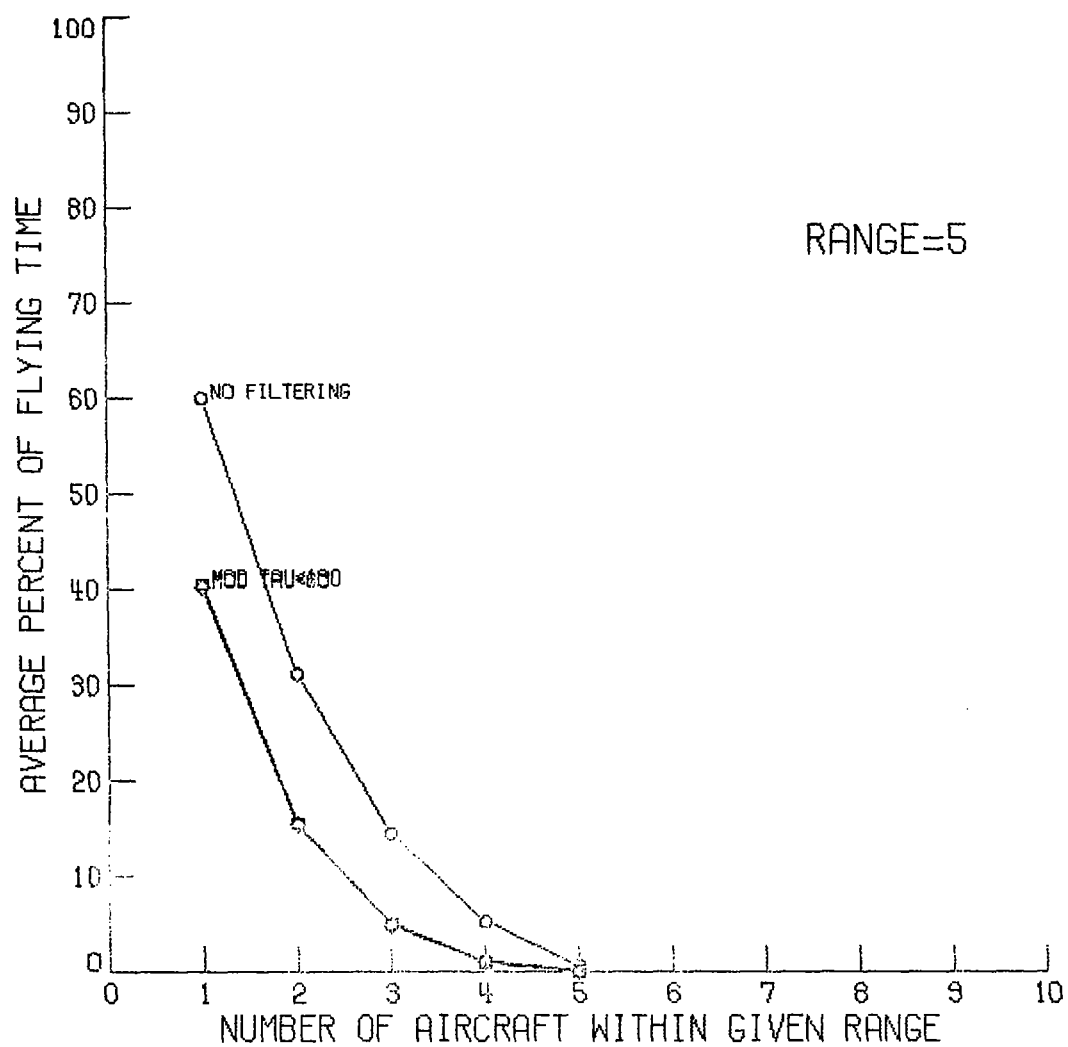
Figure 5.35. Average percentage of flying time in the terminal area vs. number of aircraft observed within a range of 5 n. mi. Curves are given for no filtering and for Modified Tau < 180 and 60 seconds.
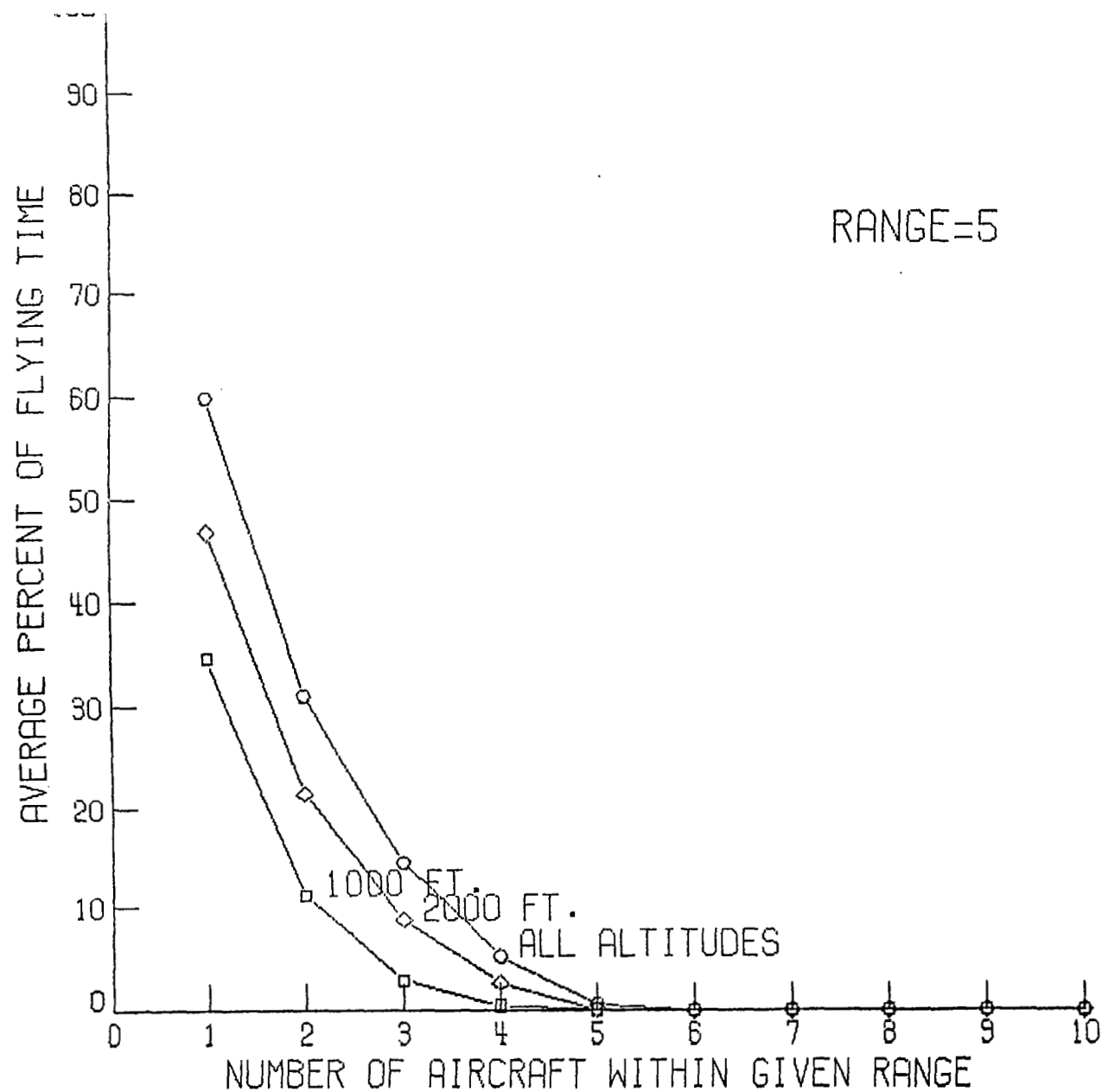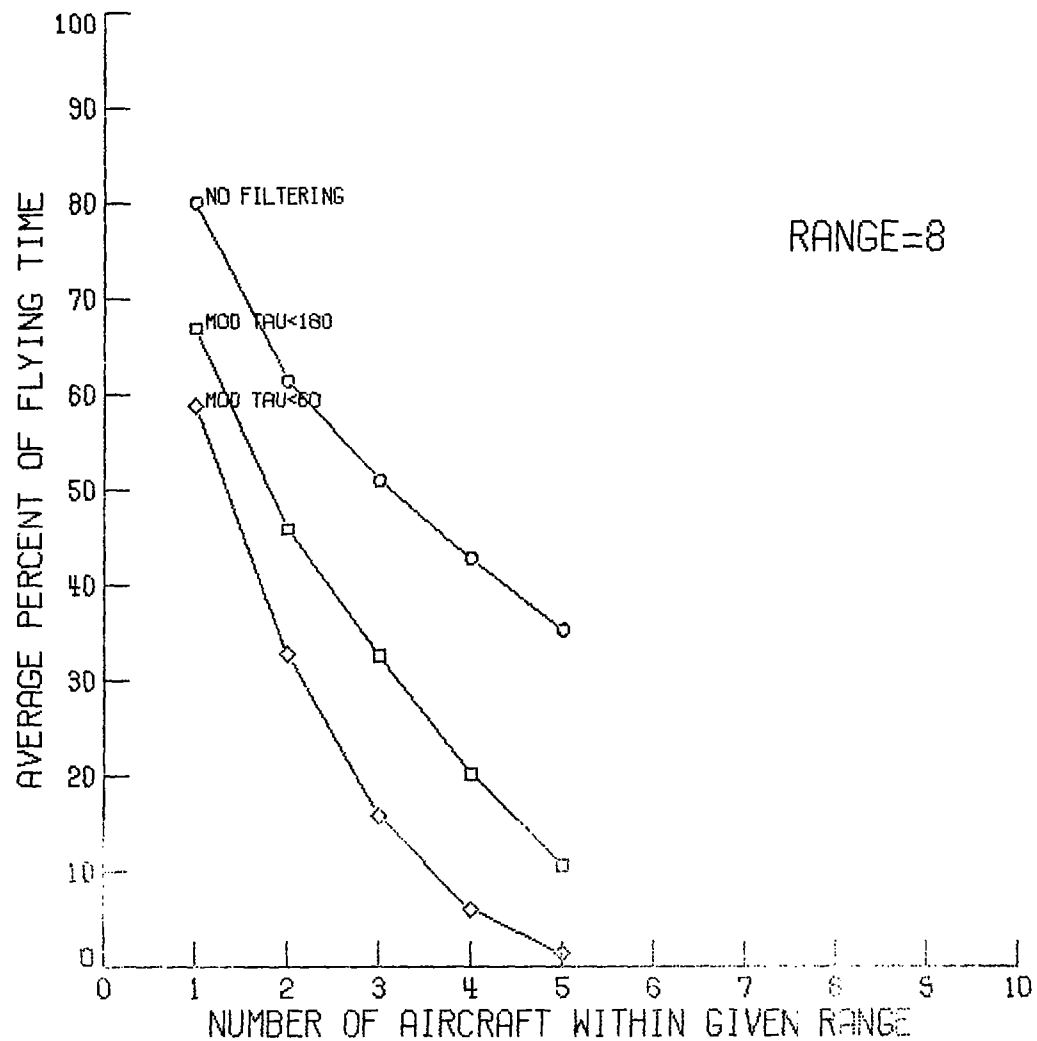
Figure 5.36. Average percentage of flying time in the terminal area vs. number of aircraft observed within a range of 8 n. mi. Curves are given for no filtering and for Modified Tau < 180 and 60 seconds.

100

90

80 — AVERAGE PERCENT OF FLYING TIME

70

o NO FILTERING

60

MOD TAU<180

MOD TAU<60

50

40

30

20

10

0

RANGE=10

0   1   2   3   4   5   6   7   8   9   10
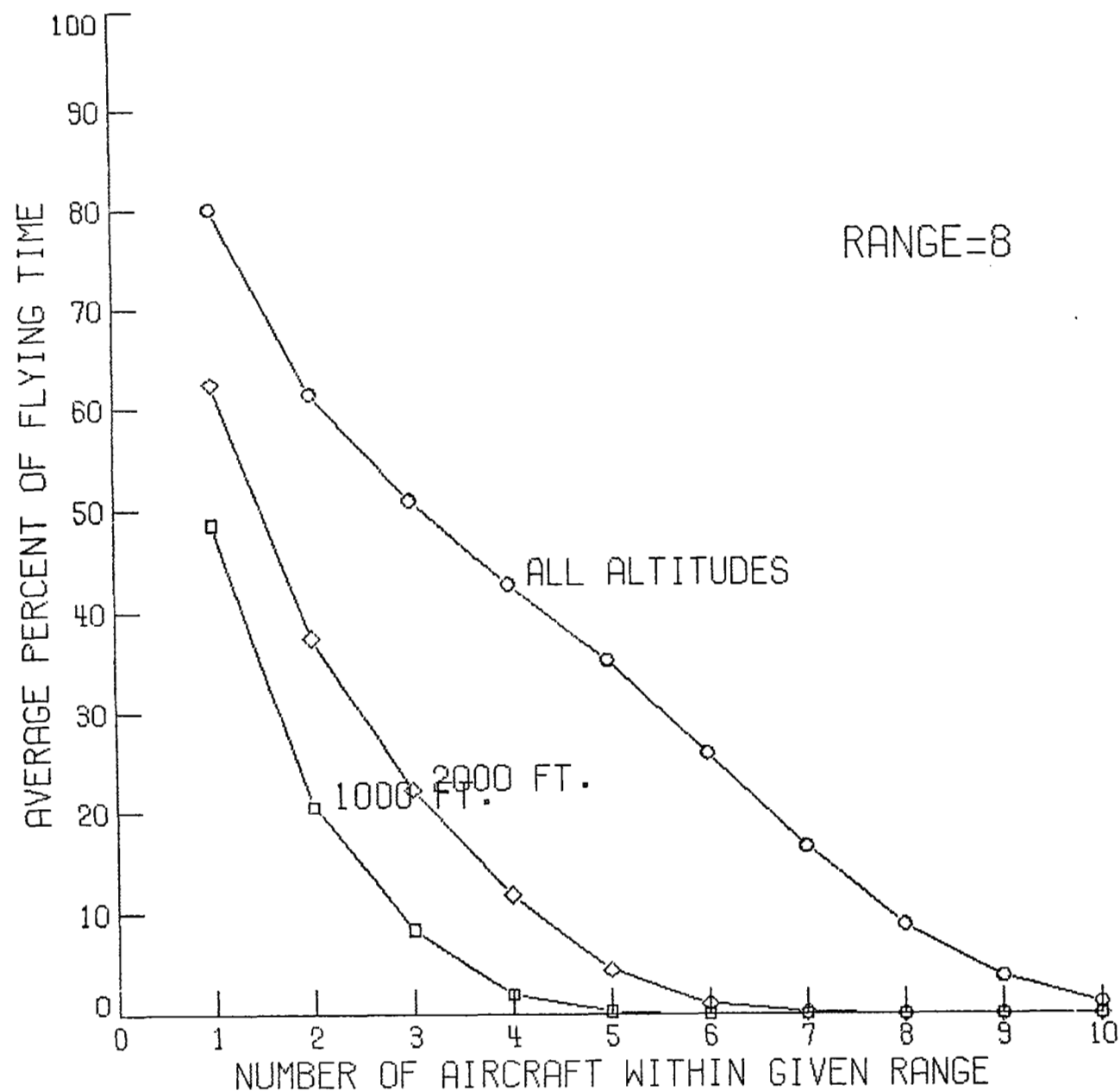
NUMBER OF AIRCRAFT WITHIN GIVEN RANGE
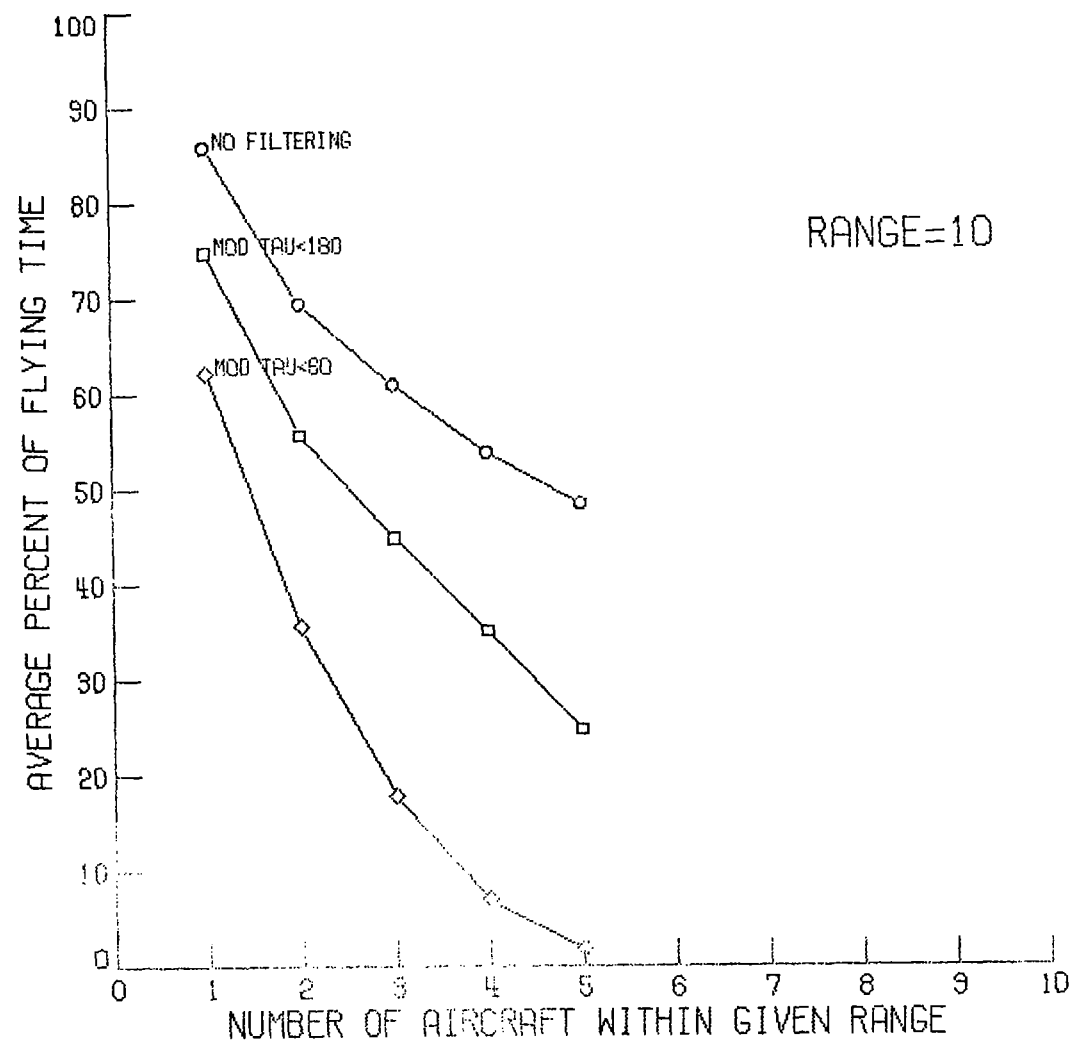
Figure 5.37. Average percentage of flying time in the terminal area vs. number of aircraft observed within a range of 10 n. mi. Curves are given for no filtering and for Modified Tau < 180 and 60 seconds.
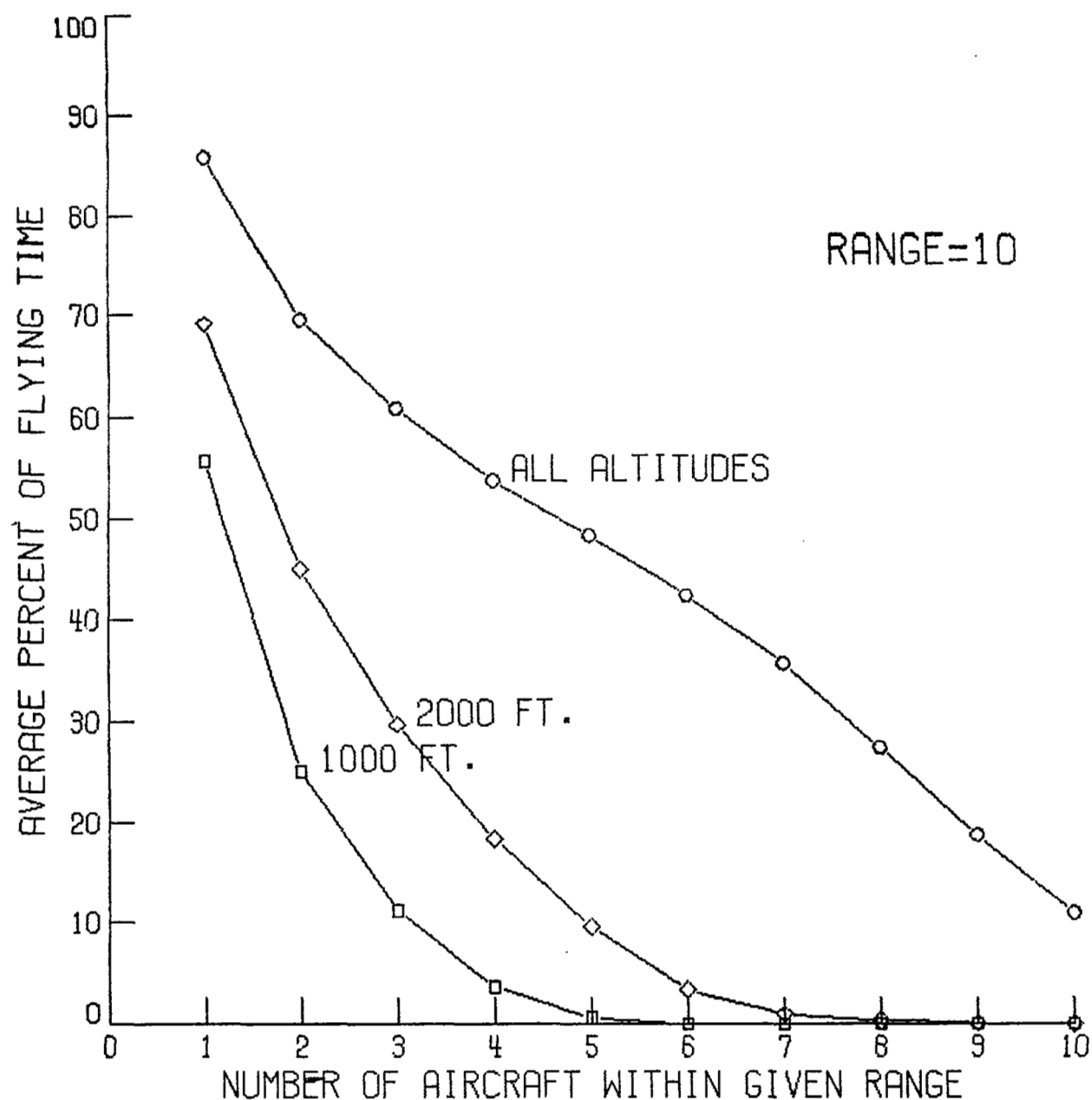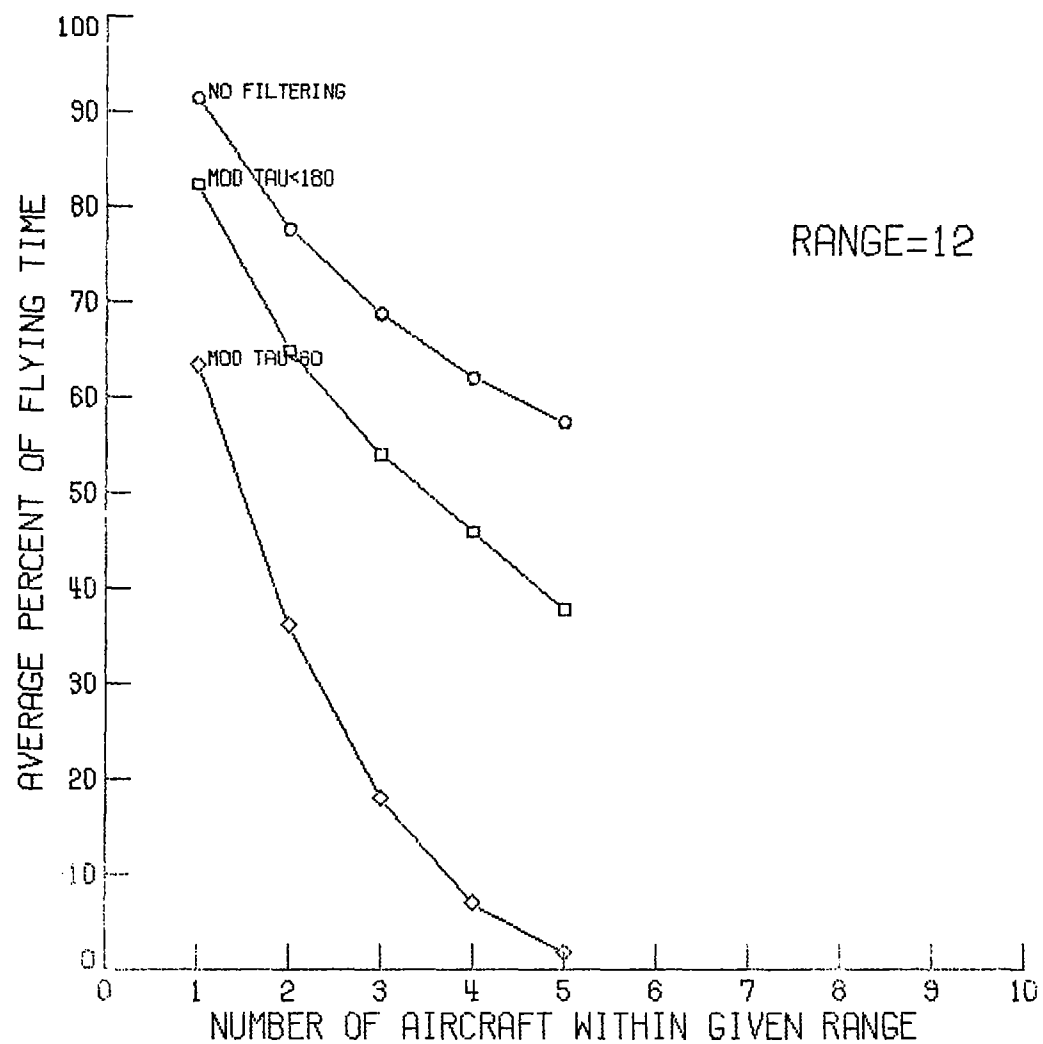
Figure 5.38. Average percentage of flying time in the terminal area vs. number of aircraft observed within a range of 12 n. mi. Curves are given for no filtering and for Modified Tau < 180 and 60 seconds.

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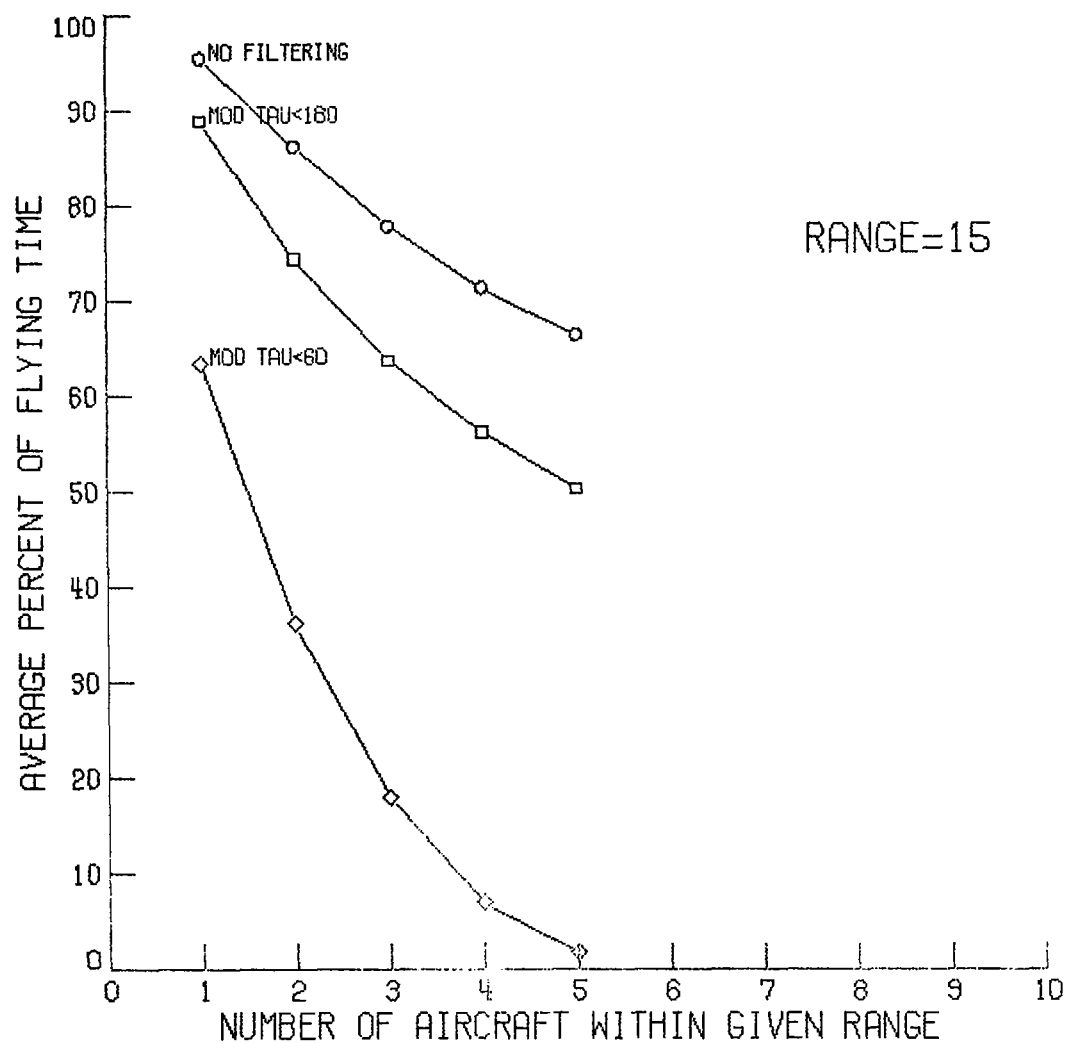
Figure 5.39. Average percentage of flying time in the terminal area vs. number of aircraft observed within a range of 15 n. mi. Curves are given for no filtering and for Modified Tau < 180 and 60 seconds.
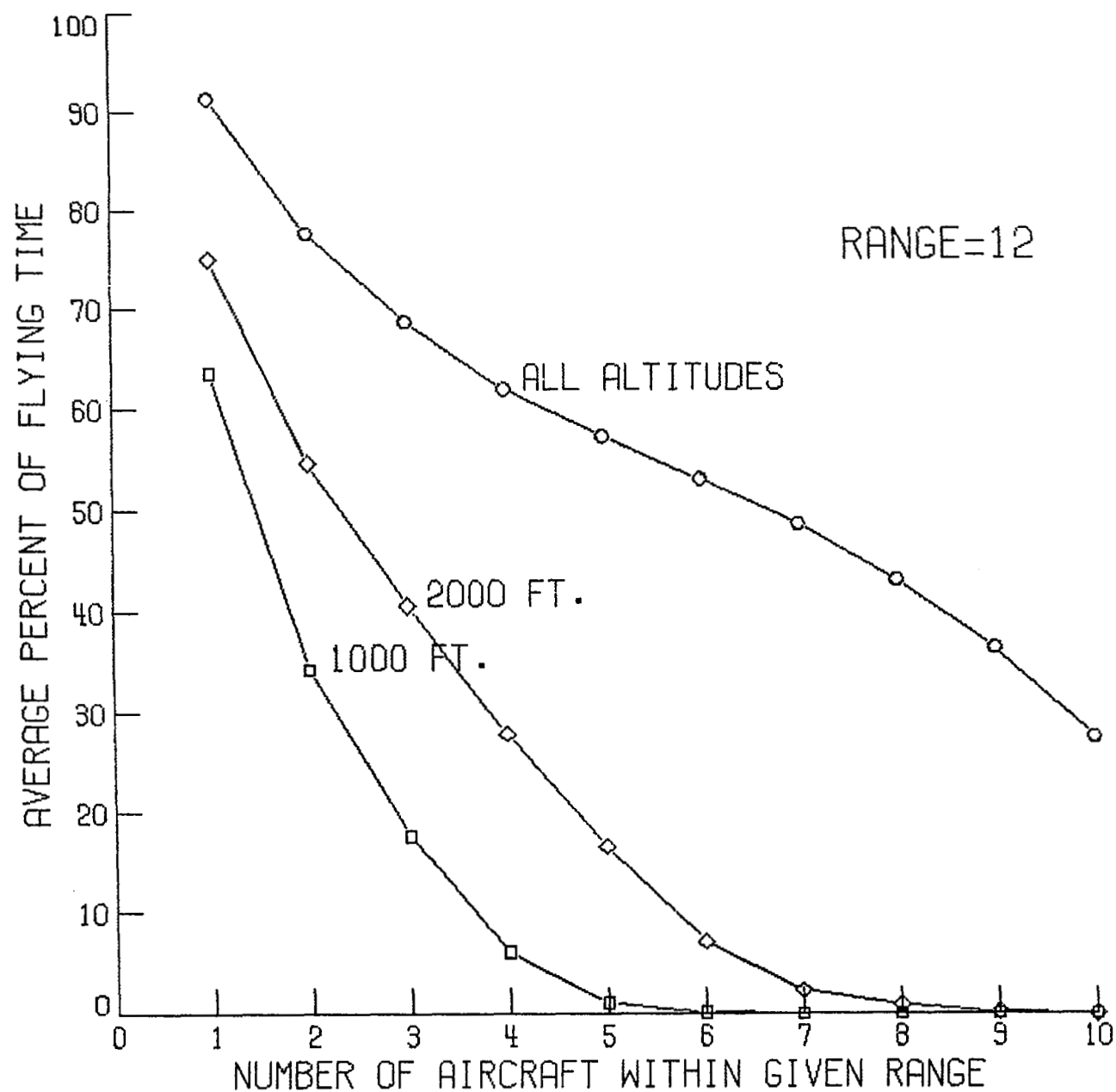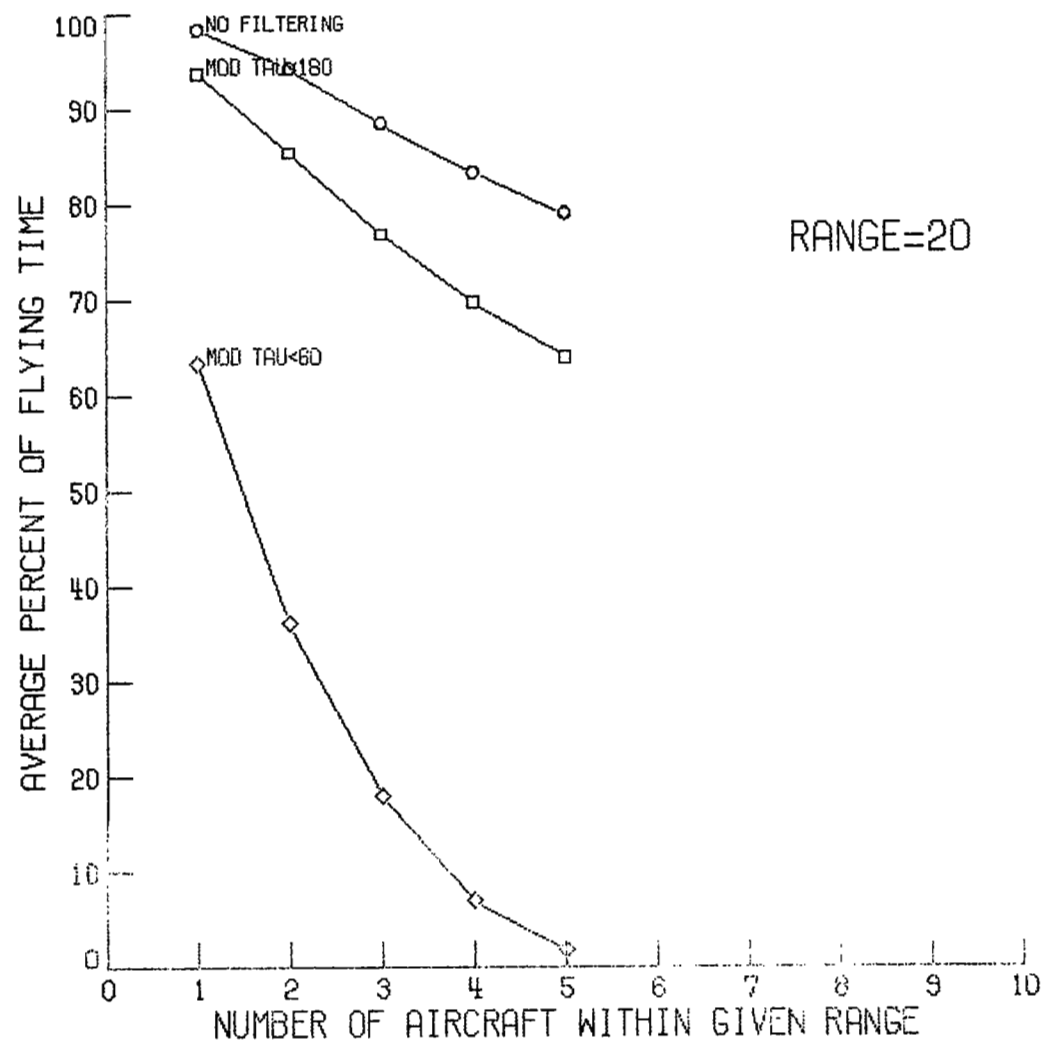
Figure 5.40. Average percentage of flying time in the terminal area vs. number of aircraft observed within a range of 20 n. mi. Curves are given for no filtering and for Modified Tau < 180 and 60 seconds.
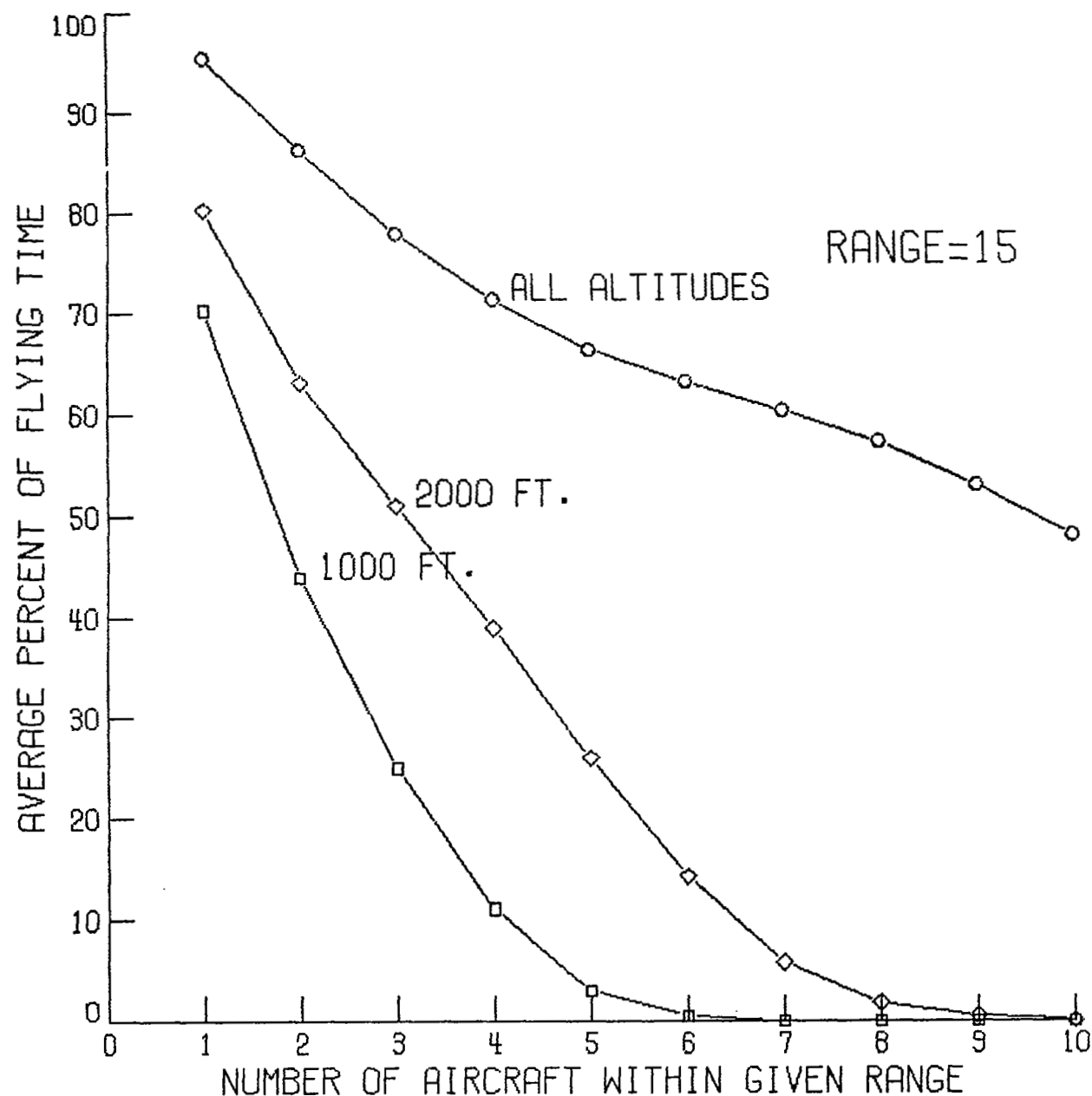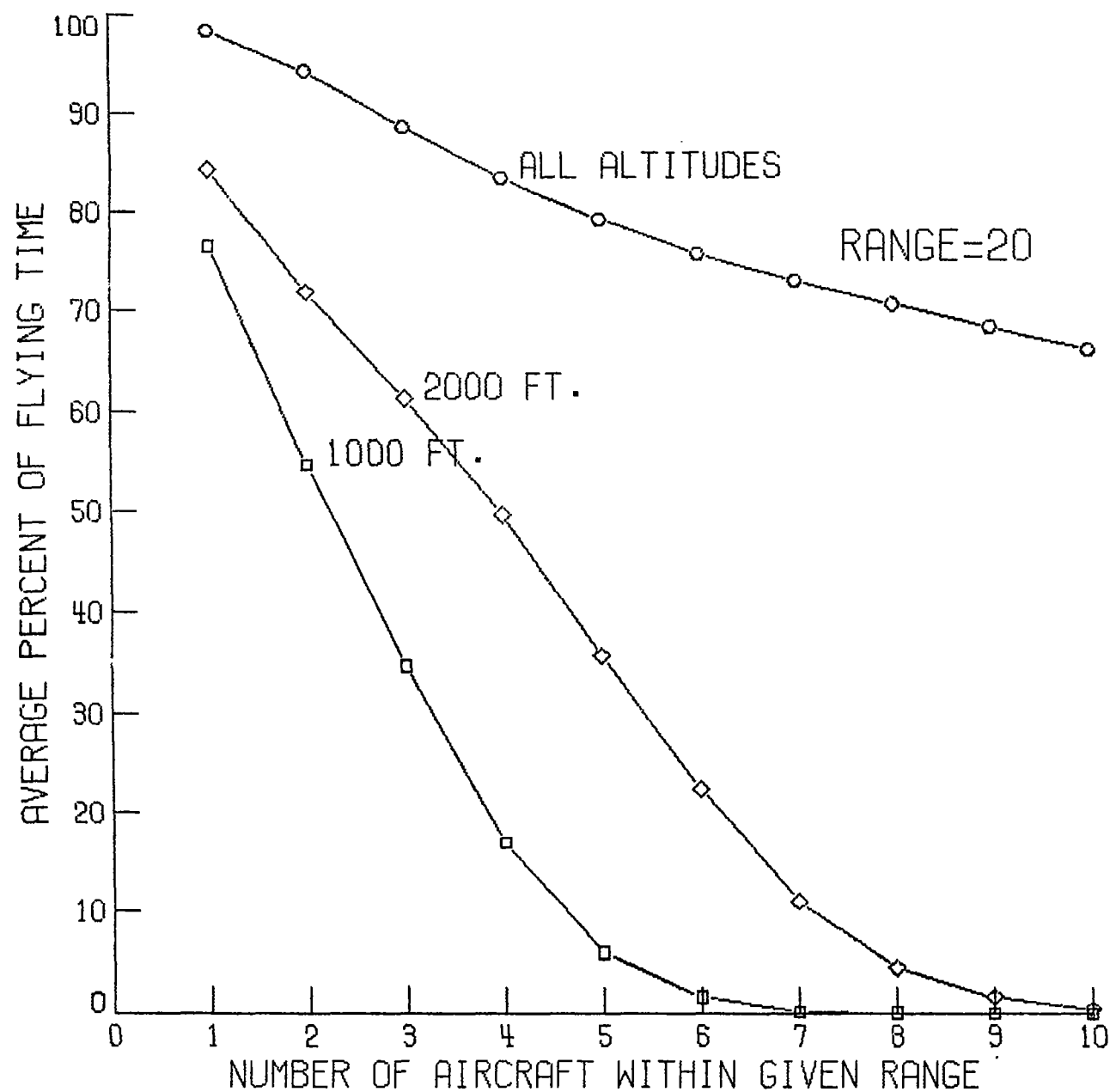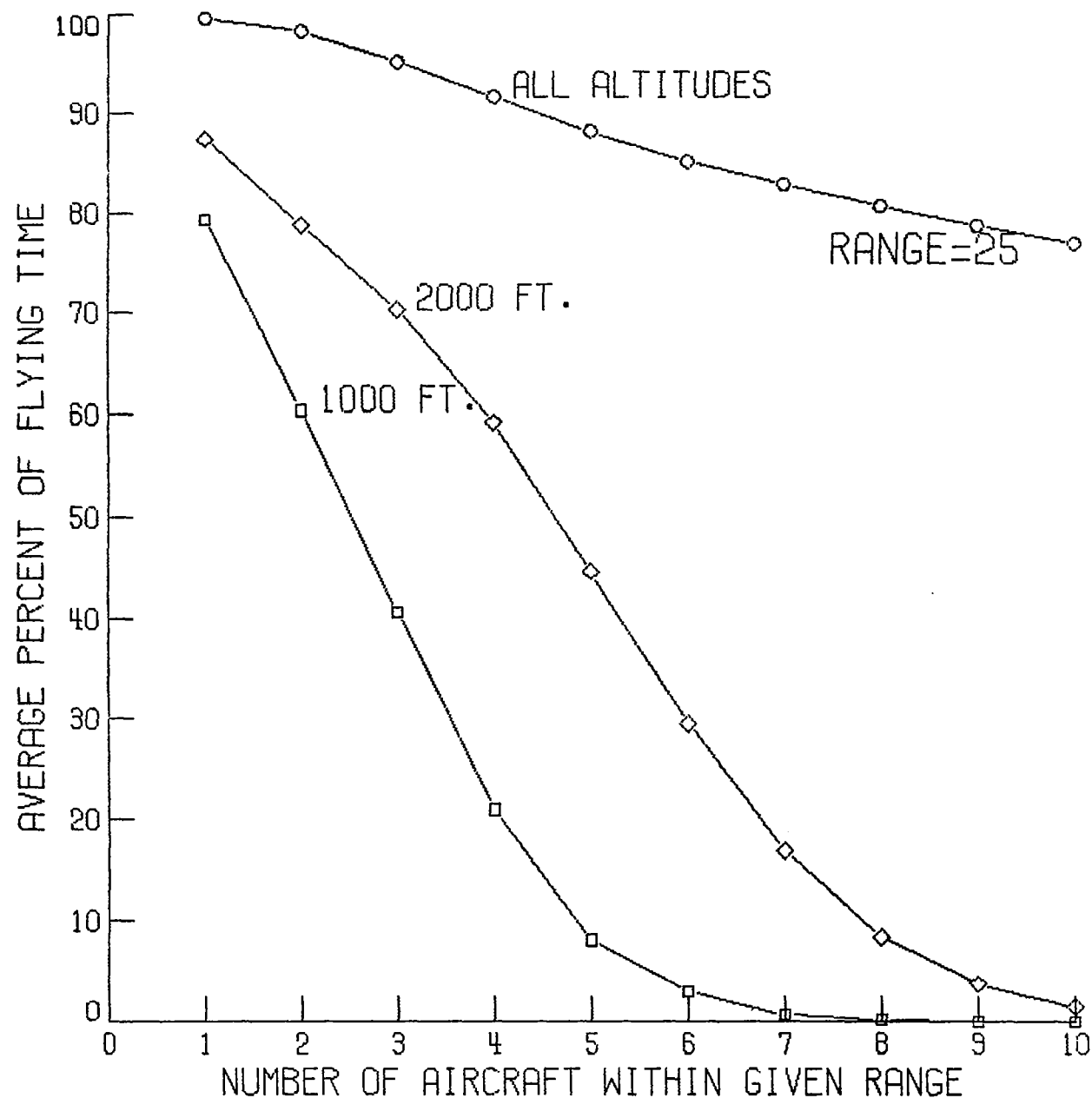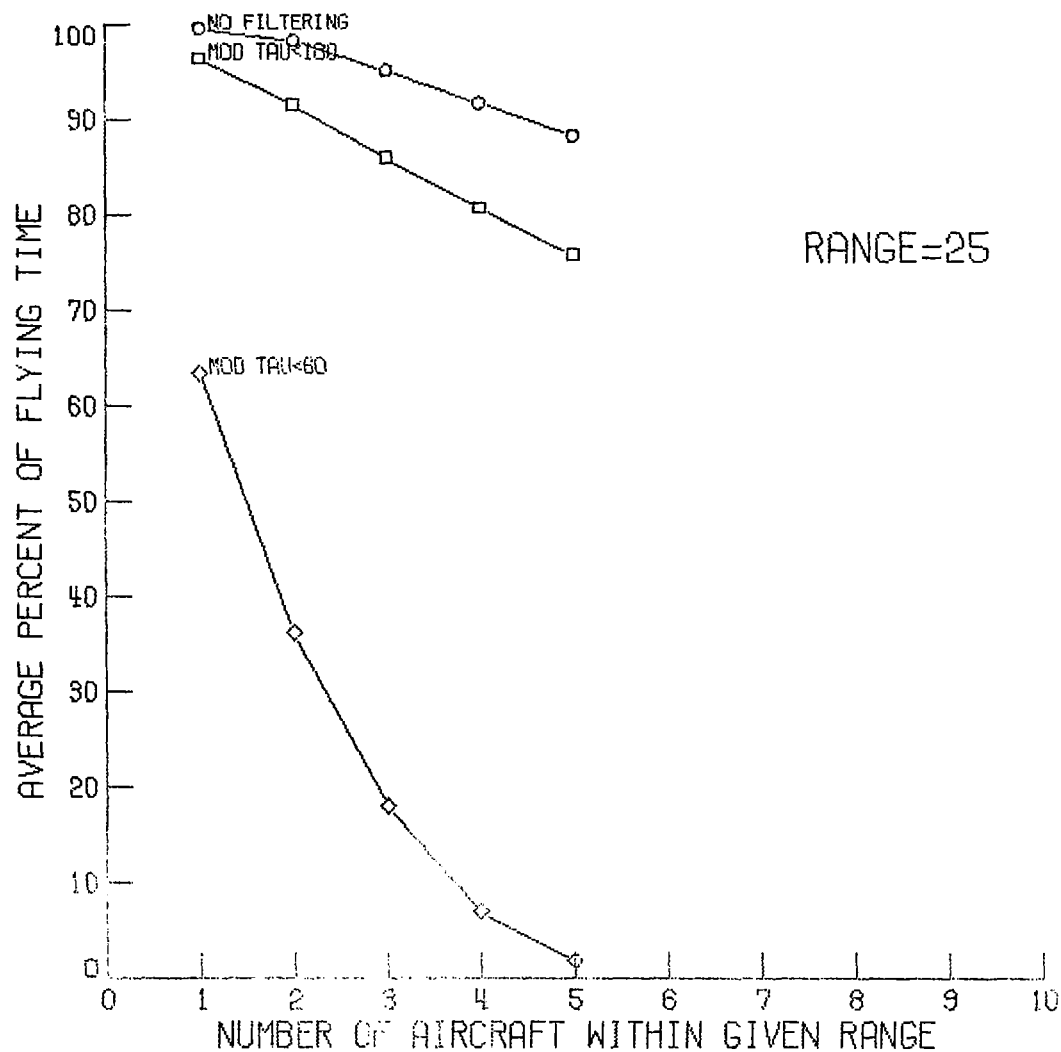
Figure 5.41. Average percentage of flying time in the terminal area vs. number of aircraft observed within a range of 25 n. mi. Curves are given for no filtering and for Modified Tau < 180 and 60 seconds.

6.0 ARTS III DATA BASE

With the cooperation of the Federal Aviation Administration,
radar tapes from the radar at the Miami and Atlanta terminal areas were
obtained. Times and dates of the data tapes are as follows:

Table 6.1 Radar Data Obtained

Data	Date	Time (E.S.T.)	Avr. A/C per radar scan
Atlanta #1	1/5/82	04:50P-11:41A	27.3
Atlanta #2	1/6/82	11:53A-05:50P	31.6
Miami #1	12/17/81	11:44A-03:12P	34.6
Miami #2	12/18/81	11:29A-02:57P	29.5
Atlanta Sim(for comparision)			24.9

These times of day generally represent busy periods at the two
terminal areas.

Data selected for analysis consisted of a two hour period
(1800 scans) starting at the beginning time of the data tapes. The two
hour period was chosen to be consistent with the simulated data runs
discussed in Section 3.0.

The data tapes obtained from the ARTS radar (data extraction
tapes) are written in an extremely complex format consisting of packed
data in various 30 bit words. An example of the format and raw data
storage is shown in Figure 6.1 Several computer programs were written
by RTI personnel to decode the data and extract the pertinent
information for further analysis. These programs included:

1. A tape dump program to examine the raw data on the tapes.

2. A diagnostic program which extracted the pertinent data
blocks and determined the number of words in various blocks and
also printed out aircraft track numbers, track initiation times,
track stop time and track duration. An example of the output of
the diagnostic program is shown in Figure 6.2.

3. An initial editor which decoded the raw data tape and sorted the time-ordered data into scan periods using an algorithm based on computer time and relative azimuth from the radar.

4. A final editor which checked and refined the scan-sort, removed duplicate aircraft in a scan, removed aircraft not tracked for more than one scan and reformatted the data for the statistical analysis program.

The data on the ARTS tape is a continuous stream of data as it is received from the radar data processor. For analysis purposes, it was necessary to break the aircraft tracking data into scan intervals to be consistent with the format of the data analysis programs. Hence, two editing programs were written to incorporate a scan selection algorithm which detected the aircraft in a single radar scan and separated the data into blocks representing one scan interval per block. Each data tape was processed through the editing programs resulting in a data tape formatted similar to the simulated data tape and containing data as shown in Figure 6.3 These data were then placed in a consistent format for the statistical analysis program and the data analyzed as described in Section 4.0.

The traffic density over the two hour period analyzed was calculated for each data tape and is shown in Table 6.1 as the average number of aircraft tracked per radar scan. An indication of the traffic density can be seen from Figures 6.4 through 6.7. These plots are similar to Figure 3.2 in that the position of the aircraft in the data set were plotted at approximately forty second intervals. As may be seen, the actual radar data are less ordered than the simulation data of Figure 3.2. It should be recalled that the simulation data does not include overflights or aircraft operations at other airports in the vicinity of the terminal area. As discussed in Section 7, the statistics from the simulation and the radar tapes agree favorably, although it was evident that the simulated traffic is more ordered than the actual radar traffic data. For the Atlanta case, it should also be noted that the same runways (9L and 9R) are being used in the radar data base as were used for generation of the simulated data base.

CTST Word

29	28	27	26	25	24	23	22	21	20	19	18	17	16	15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Test and Set		ENROUT Status				ENROUT Time Field						HST			SY	UT		A	TP	Prime Contr. / Handoff Rec. / Handoff Sender					ARTS III Contr. / 0 if ARTCC Controlled					

RGAZT Word

29	28	27	26	25	24	23	22	21	20	19	18	17	16	15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Azimuth (BAMS)													IC	C	Range (NM) LSB = 1/16 NM										Firmness				

CORDT Word

29	28	27	26	25	24	23	22	21	20	19	18	17	16	15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
$\pm Y_p$ (NM) LSB = 1/256 NM															$\pm X_p$ (NM) LSB = 1/256 NM														

XYDOT Word

29	28	27	26	25	24	23	22	21	20	19	18	17	16	15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Entry Fix												Exit Fix																	
$\pm$ Y MSB (bit 28) = 450 Kt												$\pm$ XMSB (bit 13) = 450 KTs																	

TIMET Word

29	28	27	26	25	24	23	22	21	20	19	18	17	16	15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Message Number												Time of Last Correlation (if UT = 01)																	

ABEAT Word

29	28	27	26	25	24	23	22	21	20	19	18	17	16	15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
NT		Assigned Beacon Code												T.T. 01 / Associated T.T. #1								T.T. #2 / Parent Track 0							

Fig 6.1 Example of the technique of data packing used on the raw data tapes. The above represents only a few of the 30 bit packed words in the data base.

```
NUMBER OF A/C TRACKED =        742
  TRK NO.      ACID      START TIME        END TIME
     165     N552TF      78652.76         78891.32         238.56
      23     N39R        78652.81         79055.38         402.56
      76     DL452       78652.82         78676.20          23.38
      99     PNL405      78652.94         78807.45         154.51
      60     DL444       78653.09         79189.73         536.63
      20     DL466       78653.52         79441.52         788.00
      25     DL221       78653.52         79259.04         605.52
      56     ASO306      78653.90         79780.49        1126.59
      32     DL1004      78654.11         79151.44         497.33
      19     NW755       78654.70         79352.60         697.91
      40     DL1002      78655.04         78968.97         313.93
      33     RC273       78655.05         79071.91         416.87
      98     DL559       78655.13         78772.13         117.00
      41     EA1628      78655.28         78908.30         253.02
      27     DL1740      78655.28         78856.69         201.41
      34     DL1012      78655.46         79054.79         399.33
      43     DL1667      78655.46         78908.89         253.43
      29     DL145       78655.47         78805.93         150.46
      51     DL1125      78655.47         78735.02          79.55
      46     OTIS11      78655.48         78977.92         322.45
      53     EA232       78655.48         78669.52          14.05
      28     OZ631       78655.72         79119.85         464.13
      37     EA289       78655.86         79339.30         683.44
      69     ASO507      78656.01         78660.88           4.87
      36     EA101       78656.02         79227.00         570.98
      85     DL1155      78656.02         79020.59         364.58
      93     DL254       78656.45         78712.62          56.16
     147     DL1105      78656.79         79165.47         508.68
     105     DL710       78656.80         78684.85          28.05
      18     DL131       78657.03         79437.56         780.53
      16     PI259       78657.04         79549.85         892.81
      17     RC372       78657.04         79525.73         868.69
       3     DL551       78727.85         79717.57         989.72
       5     N34976      78750.09         79048.96         298.87
     192     N12831      78796.18         79296.75         500.57
      71     SALTY41     78820.86         79249.73         428.87
       0     EA976       78846.03         79834.55         988.52
       1     N6711G      78878.80         80672.98        1794.19
     186     N60Y        78881.53         79246.02         364.48
     177     N1579R      78961.94         79863.37         901.43
     187     PI291       78962.81         79958.31         995.50
     193     N897D       78989.87         79910.18         920.31
     191     N90BB       79022.05         79653.49         631.45
      31     ASO904      79098.21         80006.41         908.20
     178     N13WF       79233.16         79499.13         265.97
     176     N2735R      79241.34         80205.75         964.41
     175     RC141       79270.66         80149.00         878.34
     174     DL348       79380.68         80101.31         720.63
     157     N079        79390.06         79688.88         298.81
     141     EA908       79495.62         79949.09         453.47
```

Fig 6.2 Example of output of a portion of the tape diagnostic program. The track
    number, ID, start time, end time, and duration are provided for each aircraft
    tracked by the radar (742 A/C for the above data).

```
                3 31 1 1
 1 11.77   2.45 265.  78666.13 10 1   19.7-250.4    12.
 2 40.61   9.47 354.  78666.14 10 1  423.8 -13.8    13.
 3 22.70 18.13 292.  78666.39  2 1-380.8 -95.4    38.
 4 34.86 31.35 320.  78666.40  2 1-228.0-242.7    42.
 5 30.91 24.55 345.  78666.40  2 1-277.8-223.2    38.
 6  1.74   2.55  37.  78666.54 10 1   73.4 173.8    56.
 7 12.67 21.30 147.  78666.83 12 1   70.7 273.1    59.
 8  8.88 23.264095.  78666.86  3 0 -42.5 150.6    69.
 9 15.78 39.64 357.  78666.86 10 1  252.8 330.1    68.
10  3.09 36.58 150.  78666.98 10 1  122.1 165.6    85.
11-16.93 21.05 275.  78667.56  2 1  147.9-234.7   129.
12 -4.81   5.91 272.  78667.56  2 1  120.4-150.8   129.
13 -9.50   5.98  64.  78667.91 10 1-101.2  54.4   148.
14 -5.00   0.07 258.  78668.15  2 1 -30.0-169.2   179.
15-23.68-23.62 265.  78668.73  2 1  290.8  13.4   225.
16 -4.18 -7.32  66.  78669.06  2 1   12.2-184.8   240.
17 -6.39-15.82  82.  78669.20  2 1  200.1  31.6   248.
18 -8.03-31.81 608.  78669.20 10 1-235.6-310.1   256.
19 -1.25-11.00  57.  78669.32  2 1  213.4  -0.2   263.
20  0.09 -9.21  56.  78669.50  2 1   43.1 176.4   271.
21  2.67-19.51  87.  78669.51  2 1-174.1 -34.6   278.
22  1.34-13.12  80.  78669.51  2 1-188.0  11.2   276.
23  1.02 -7.23  57.  78669.51  2 1 -13.6 210.5   278.
24  0.17 -3.84  32.  78669.52  2 1  -1.4 155.6   272.
25 -0.01-32.85 326.  78669.52 13 1-168.4 -93.8   270.
26  0.17 -1.11  18.  78669.52  2 1  -2.3 134.1   279.
27  8.39-16.98 115.  78669.76  2 1-163.6 -75.0   296.
28 16.55-18.34 144.  78669.90  2 1-174.6 200.8   312.
29  4.96 -4.66 112.  78670.09  2 1 -13.2-177.0   317.
30 10.78 -9.82 337.  78670.09 10 1 -13.6-318.5   318.
32 39.62 -3.67 388.  78670.53 10 1  338.0-126.5   355.
```

Initial Numbers: 1   Scan   number
                      2   No of A/C this scan
                      3   Tape number
                      4   Constant value = 1

Columns: 1   TRACK ID (Computer assigned)
              2   X coord. (nm)
              3   Y coord. (nm)
              4   ALT/100 (ft)
              5   TIME (secs)
              6   Arrival/departure/overflight code
              7   Mode C status
              8   X velocity (kts)
              9   Y velocity (kts)
             10   AZ from radar (Deg)

Figure 6.3 Example of one scan of edited data from radar tapes. The
           data are organized into blocks, each of which are the aircraft
           appearing in a radar scan.

Figure 6.4   Plot of Atlanta #1 data set.   The position of each aircraft in a scan
is plotted at approximately 40 second intervals over a two hour period.

Figure 6.5 Plot of Atlanta #2 data set. The position of each aircraft in a scan
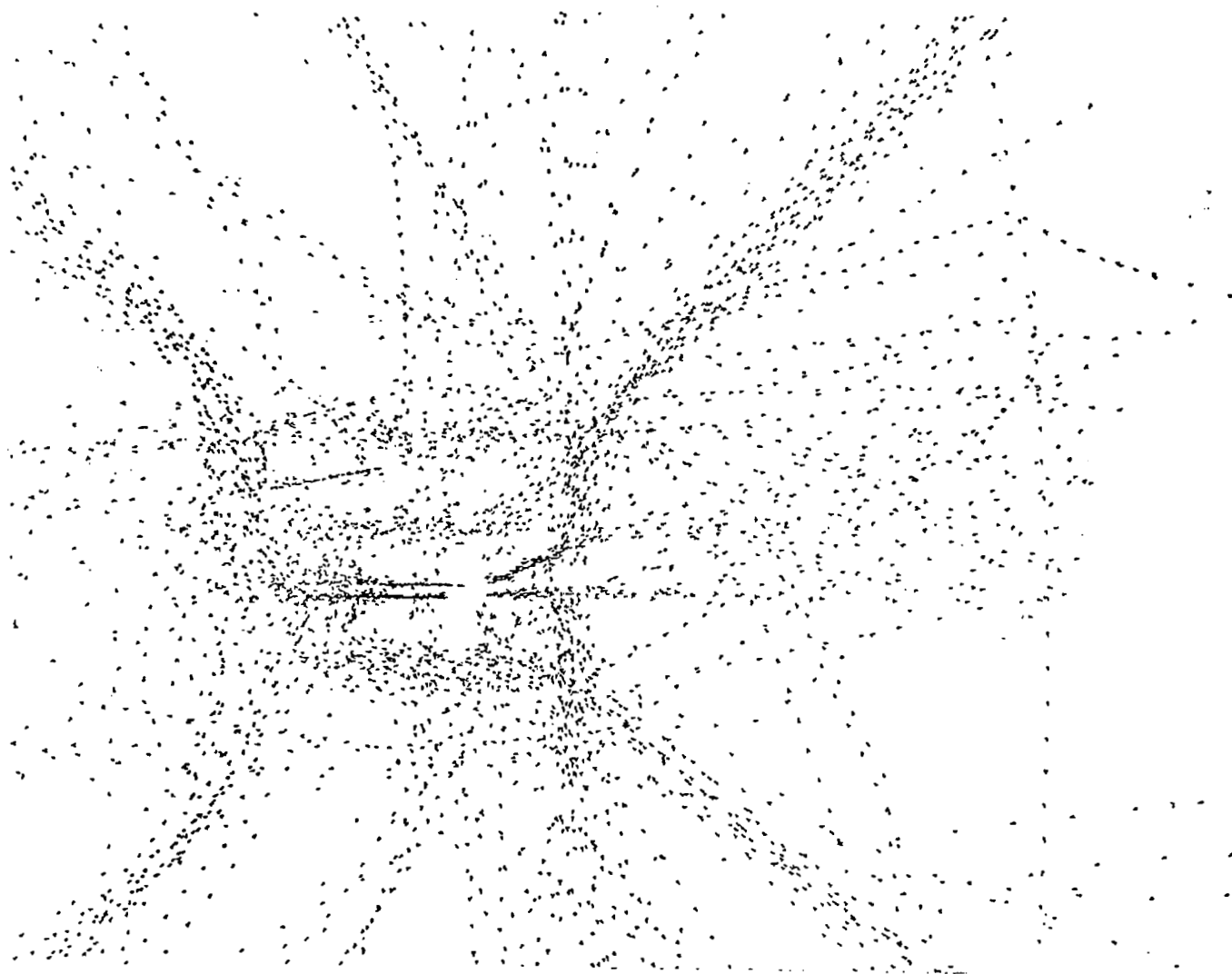is plotted at approximately 40 second intervals over a two hour period.

Figure 6.6 Plot of Miami #1 data set. The position of each aircraft in a scan is plotted
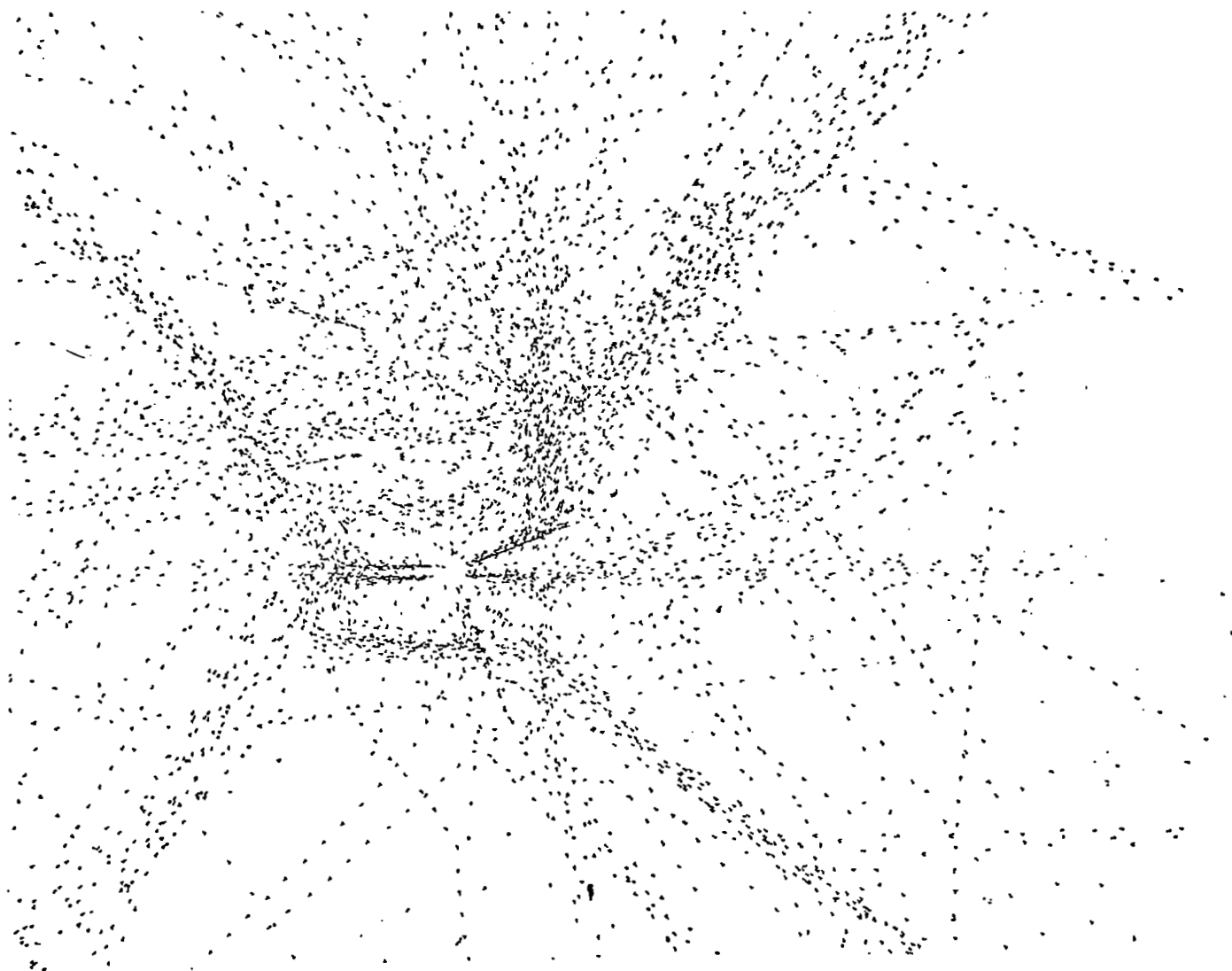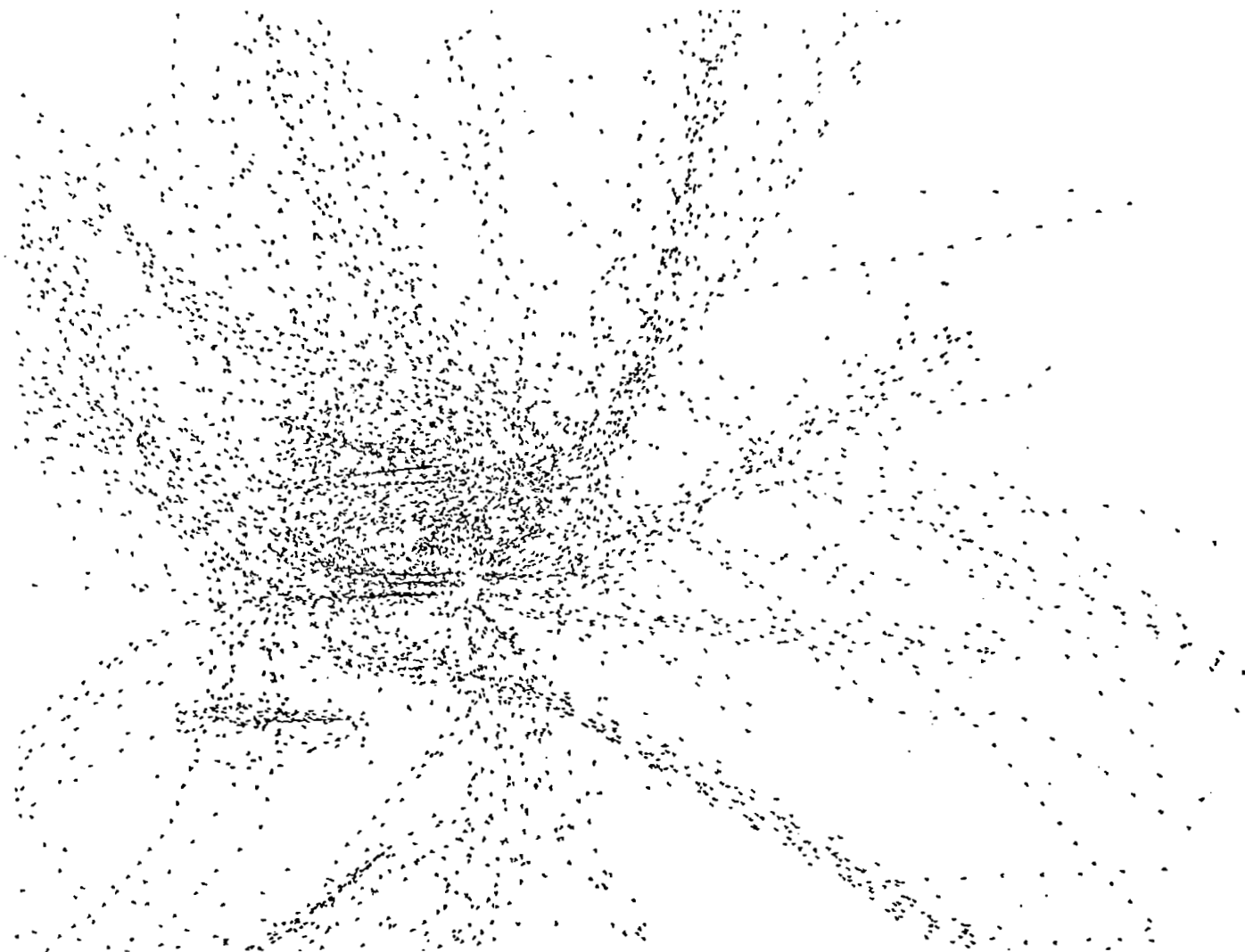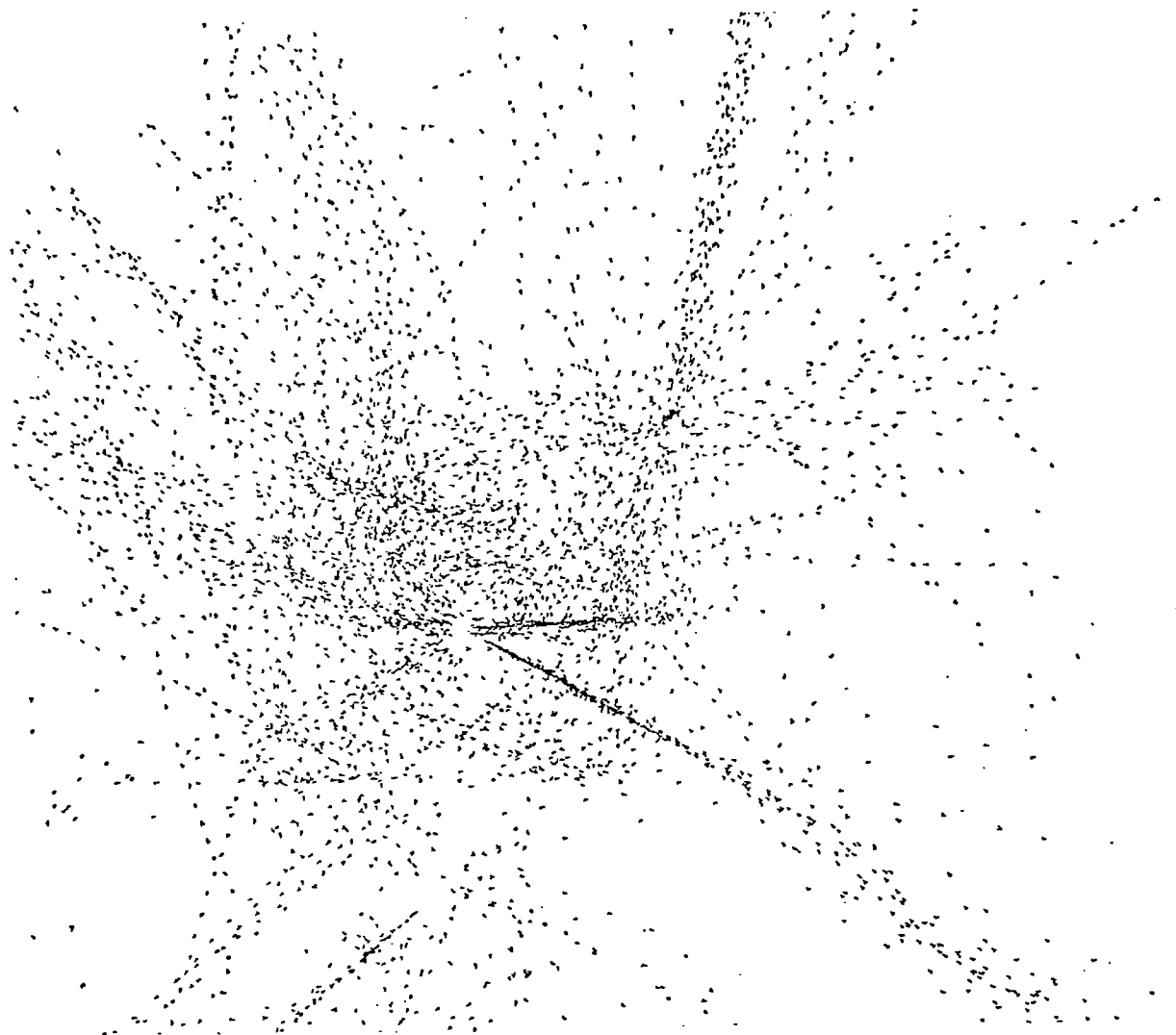at approximately 40 second intervals over a two hour period.

Figure 6.7   Plot of Miami #2 data set. The position of each aircraft in a scan is
plotted at approximately 40 second intervals over a two-hour period.

7.0 EVALUATION OF SELECTION CRITERIA USING ARTS III DATA

7.1 Targets Displayed with No Discrimination.

As discussed in Section 6, the actual radar traffic data were subjected to analyses as described in Section 4. Histograms were generated to indicate the percentage of flying time (or probability) that a randomly selected aircraft would observe from 1 to 10 simultaneous aircraft within a given range. Figures 7.1 through 7.4 show probability distributions of the probability that a randomly selected aircraft from the data base will have at least one other aircraft within the range bins given along the horizontal axis. These plots were made for Atlanta tapes #1 and #2 and Miami tapes #1 and #2. These plots can be compared with the simulated data given in Figure 5.1. As may be seen, the actual radar traffic tapes indicate a probability distribution of the same shape but with greater variance than was obtained in the simulated data. This indicates that the simulated data was somewhat more densely packed and more closely controlled than the actual traffic on the radar tapes.

Figure 7.5 through 7.8 show average percentage of flying time that a randomly selected aircraft will have another aircraft simultaneously displayed within a range value as given along the horizontal axis for no discrimination. These figures may be compared with Figure 5.5 which plots simulated data. In the simulated data, the closest aircraft (N=1) appeared within smaller range values for a larger percentage of the time. For five or more simultaneous aircraft within a given range, the simulated and actual data compare very favorably.

As an example of interpreting the data given in Figure 7.5 through 7.8, consider Figure 7.5. Using this curve, it is possible to make statements such as "for a CDTI range setting of 10 nautical miles, there will be approximately 10 aircraft observed simultaneously 3% of the time, 5 aircraft will be observed simultaneously approximately 23% of the time, and one aircraft approximately 75% of the time, under the conditions existing in the data base." The time period refers to the time under radar track in the terminal area.

7.2 Displays With Altitude Discrimination.

Figure 7.9 through 7.12 show the effect of using altitude discrimination with plus or minus 1,000 foot altitude bands used for discrimination. A plot is shown for each of the four data sets analyzed.

Figure 7.13 through 7.16 show similar curves, except in this case, a plus or minus 2,000 foot altitude band is used for discrimination. As may be seen, altitude discrimination is very effective in reducing the numbers of aircraft observed at a given range setting.

Since aircraft tend to fly at even altitudes, it may be better to use uneven altitudes for discrimination to prevent aircraft from popping in and out of the display when this discrimination feature is used. To investigate this case, the plot shown in figure 7.17 was generated to show the effect of plus or minus 2,500 foot altitude discrimination using the Atlanta #1 data base. By comparing this figure with figure 7.13, it may be seen that the statistics did not change significantly when the altitude band was increased. For this reason, it is felt that the statistics generated for plus or minus 1,000 feet and plus or minus 2,000 feet will also apply if these bands are increased by 500 feet.

7.3 Closing Velocity Discrimination.

Figures 7.18 through 7.21 show the effect of eliminating those aircraft that are not closing on the ownship. This discriminate does provide significant reduction in the number of aircraft displayed, although not as effectivly as altitude discrimination. As may be seen, closing velocity filtering appears to be more effective at larger range scale settings and for larger numbers of aircraft within a given range, as was the case with the simulated data.

7.4 Time-To-Closest-Approach Discrimination.

Since the analysis of the simulated data discussed in Section 5 indicated that time-to-closest-approach discrimination and modified time-to-closest-approach discrimination was not a strong function of the range setting on the CDTI, data for this discriminate has been presented in Figures 7.22 through 7.25 in a slightly different form than was used in Section 5.0. These figures show the values of Tau that would be observed in a randomly selected aircraft using no other discrimination. Cumulative distribution plots are shown for 1 through 10 simultaneous aircraft.

As an example of interpreting these plots, consider Figure 7.22. This plot indicates that if a Tau discriminate were used in the ownship aircraft, and if, for example, it were set at 200 seconds, there would be seven aircraft observed simultaneously with less than this value of Tau approximately 4% of the time. There would be one aircraft observed with less than this value of Tau approximately 75% of the time. Note also that these curves indicate a severe false alarm problem for alarm systems based on the Tau parameter unless some other form of discrimination is used.

Figures 7.26 to 7.29 show plots similar to those discussed above except that altitude discrimination of +/-2000 ft. is used. As may be seen, the discrimination provided by the Tau parameter is greatly improved.

7.5 Modified Time-To-Closest-Approach Discrimination.

Cumulative distribution similar to those provided above are given for the modified Tau parameter in Figure 7.30 through 7.33. Plots showing the effect of the modified Tau parameter combined with +/-2000 ft. altitude discrimination are given in Figs 7.34 to 7.37. For the modified Tau discriminate, the allowed acceleration parameter was 1/4 g (see section 2.5).

1ST CLOSEST PAIR
CASE COUNTS = 49117
NO. OF SCANS = 1796
NO FILTERING

PERCENTAGE
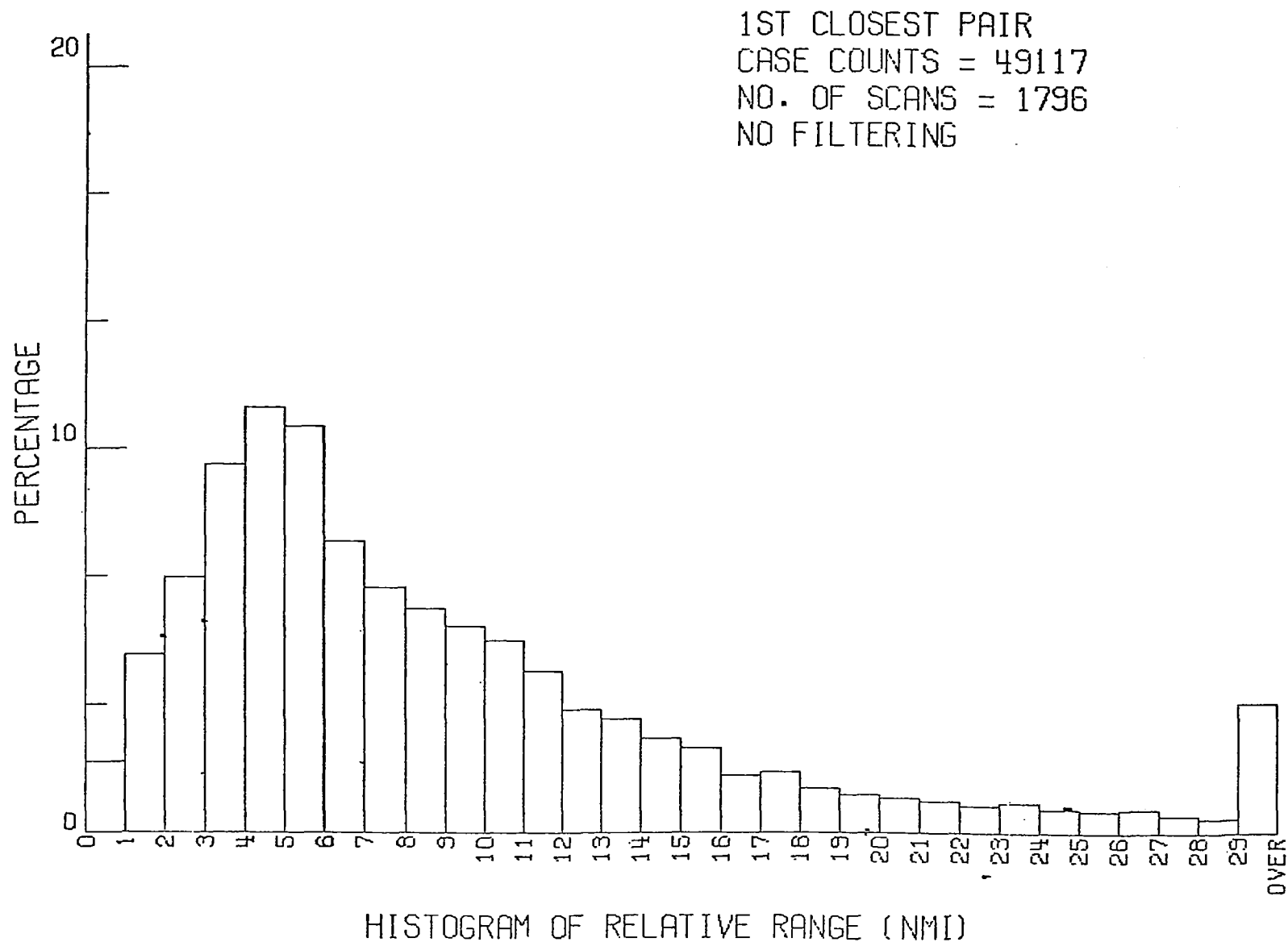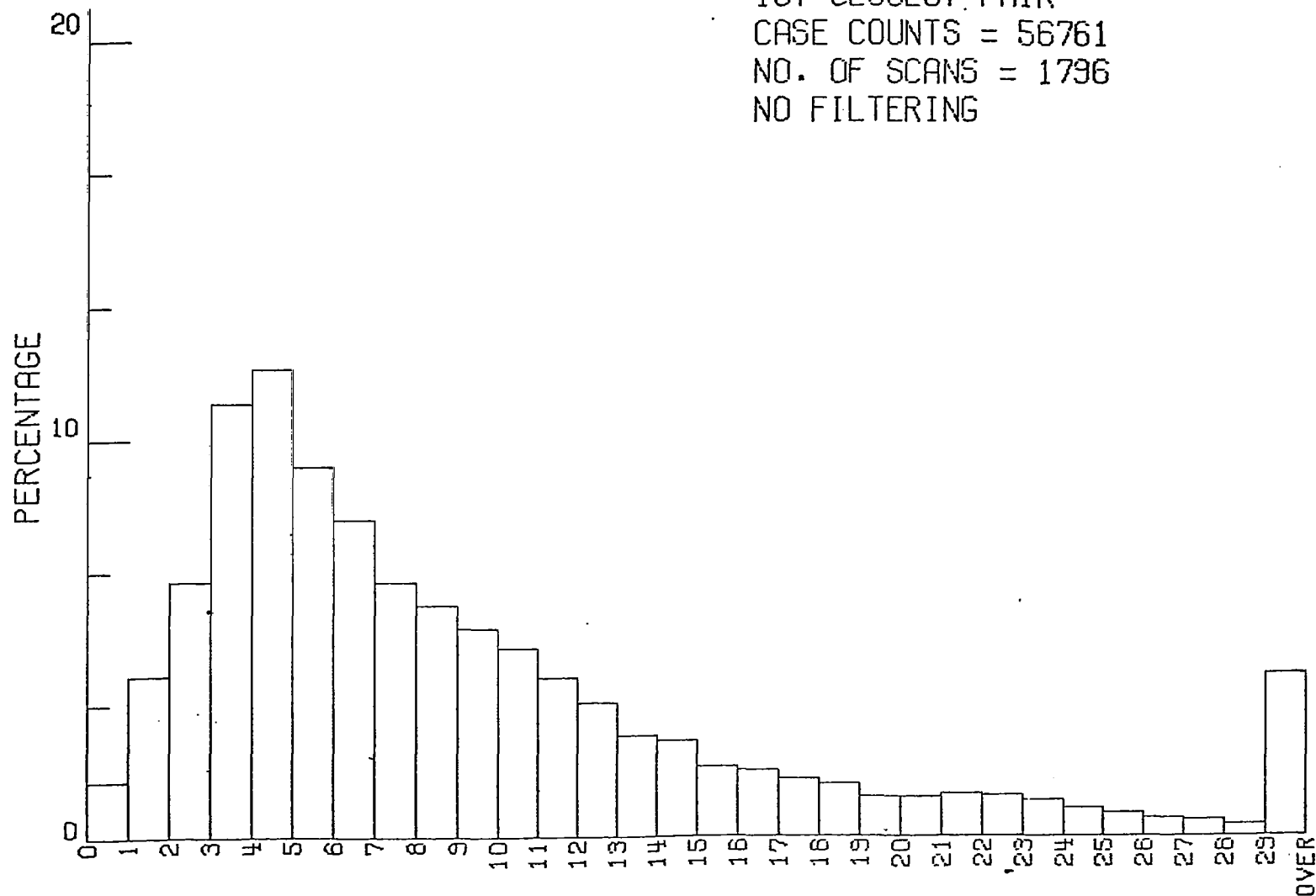
HISTOGRAM OF RELATIVE RANGE (NMI)

Figure 7.1 Histogram of the average percentage of flying time that a randomly selected
aircraft will have at least one other aircraft within the range bins shown
along the horizontal axis. No discrimination is used. Atlanta #1 data.

Figure 7.2 Histogram of the average percentage of flying time that a randomly selected aircraft will have at least one other aircraft within the range bins shown along the horizontal axis. No discrimination is used. Atlanta #2 data.
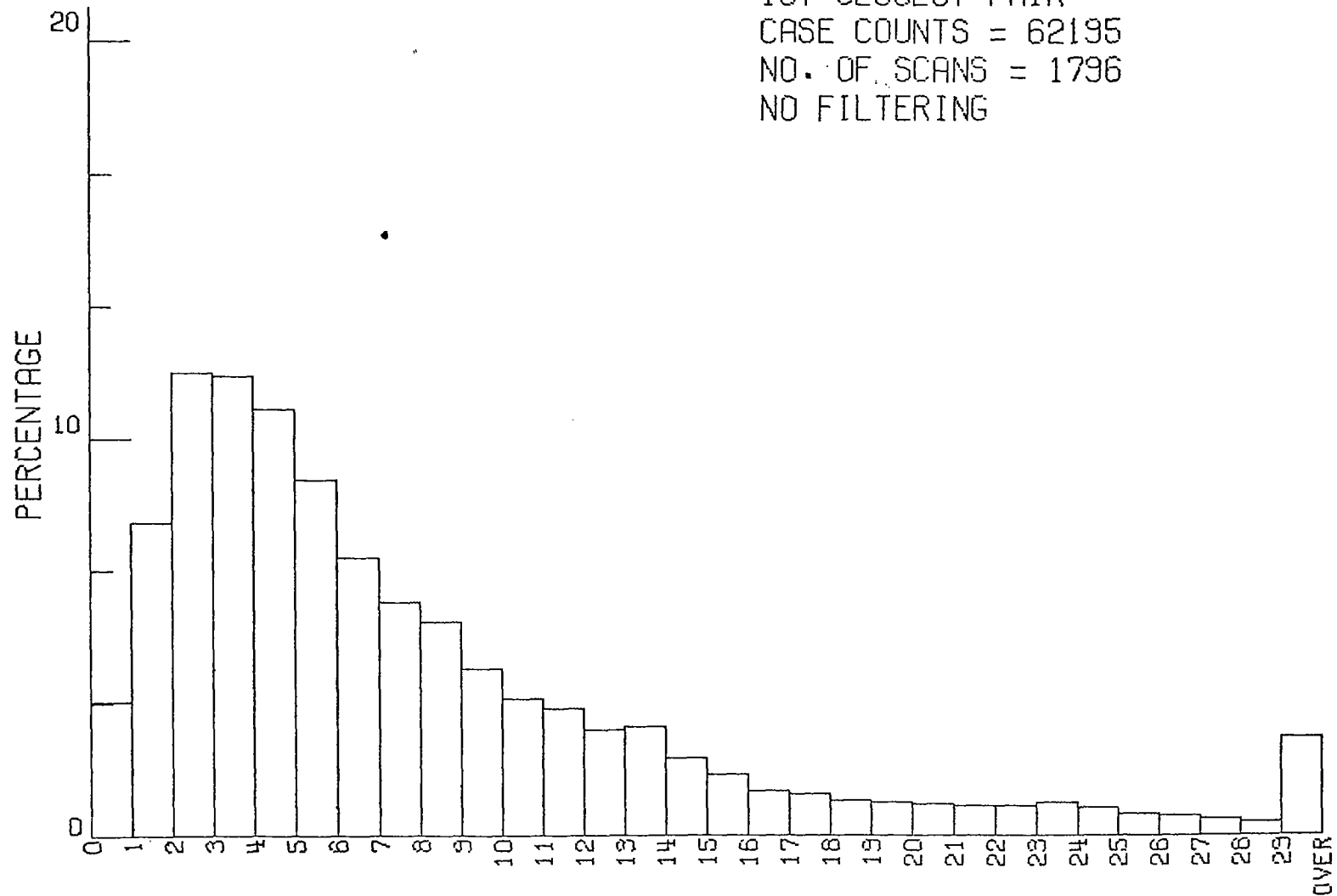
Figure 7.3 Histogram of the average percentage of flying time that a randomly selected
aircraft will have at least one other aircraft within the range bins shown
along the horizontal axis. No discrimination is used. Miami #1 data.

1ST CLOSEST PAIR
CASE COUNTS = 52961
NO. OF SCANS = 1796
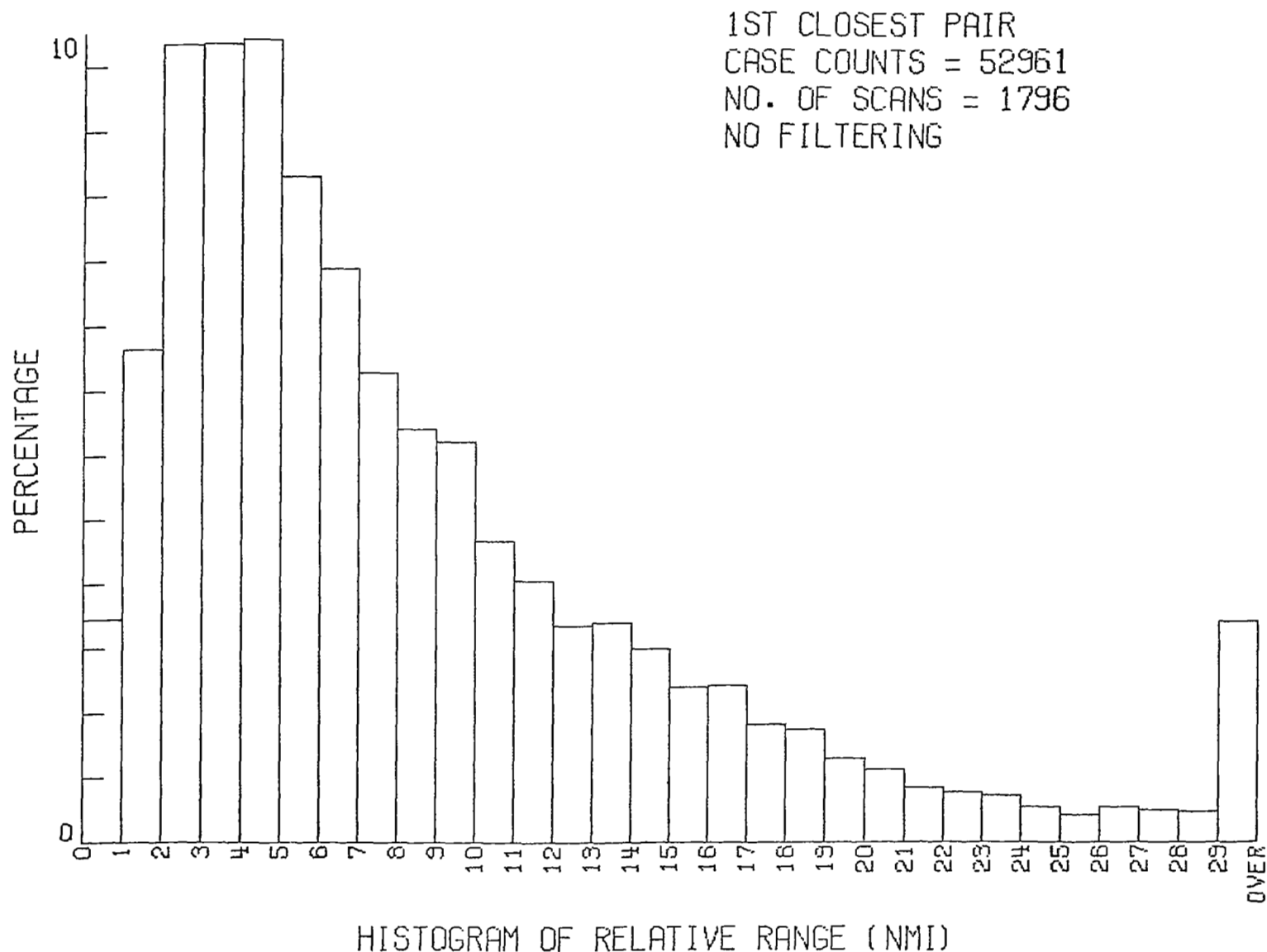NO FILTERING

HISTOGRAM OF RELATIVE RANGE (NMI)

Figure 7.4   Histogram of the average percentage of flying time that a randomly selected
aircraft will have at least one other aircraft within the range bins shown
along the horizontal axis. No discrimination is used. Miami #2 data.

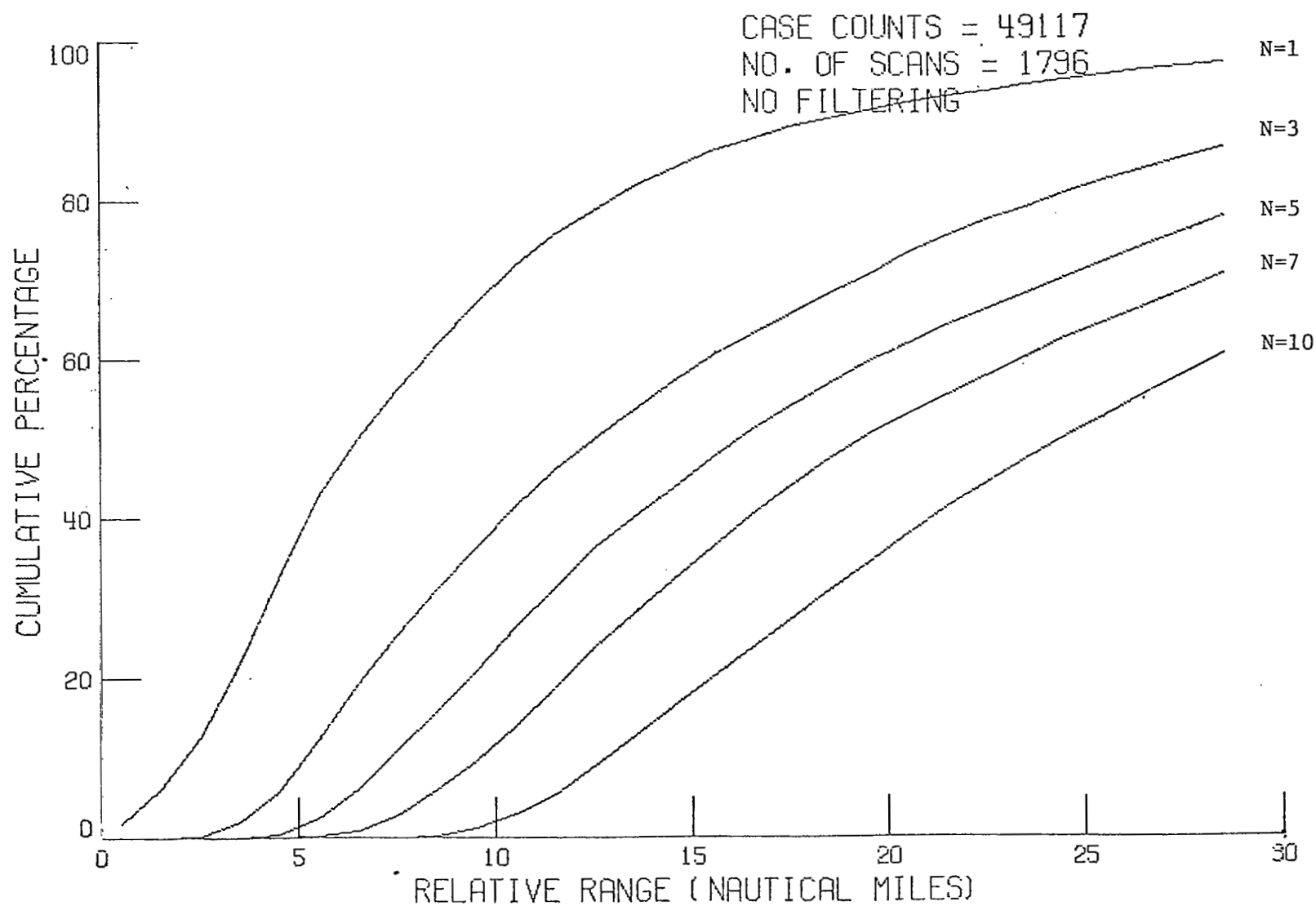Note vertical scale is different from Figures 7.1 - 7.3.

Figure 7.5 Average percent of flying time that a randomly selected aircraft will have N other aircraft simultaneously displayed within a range value given along the horizontal axis. No discrimination is used. Atlanta #1 data.

Figure7.6 .Average percent of flying time that a randomly selected aircraft
will have N other aircraft simultaneously displayed within a
range value given along the horizontal axis. No discrimination
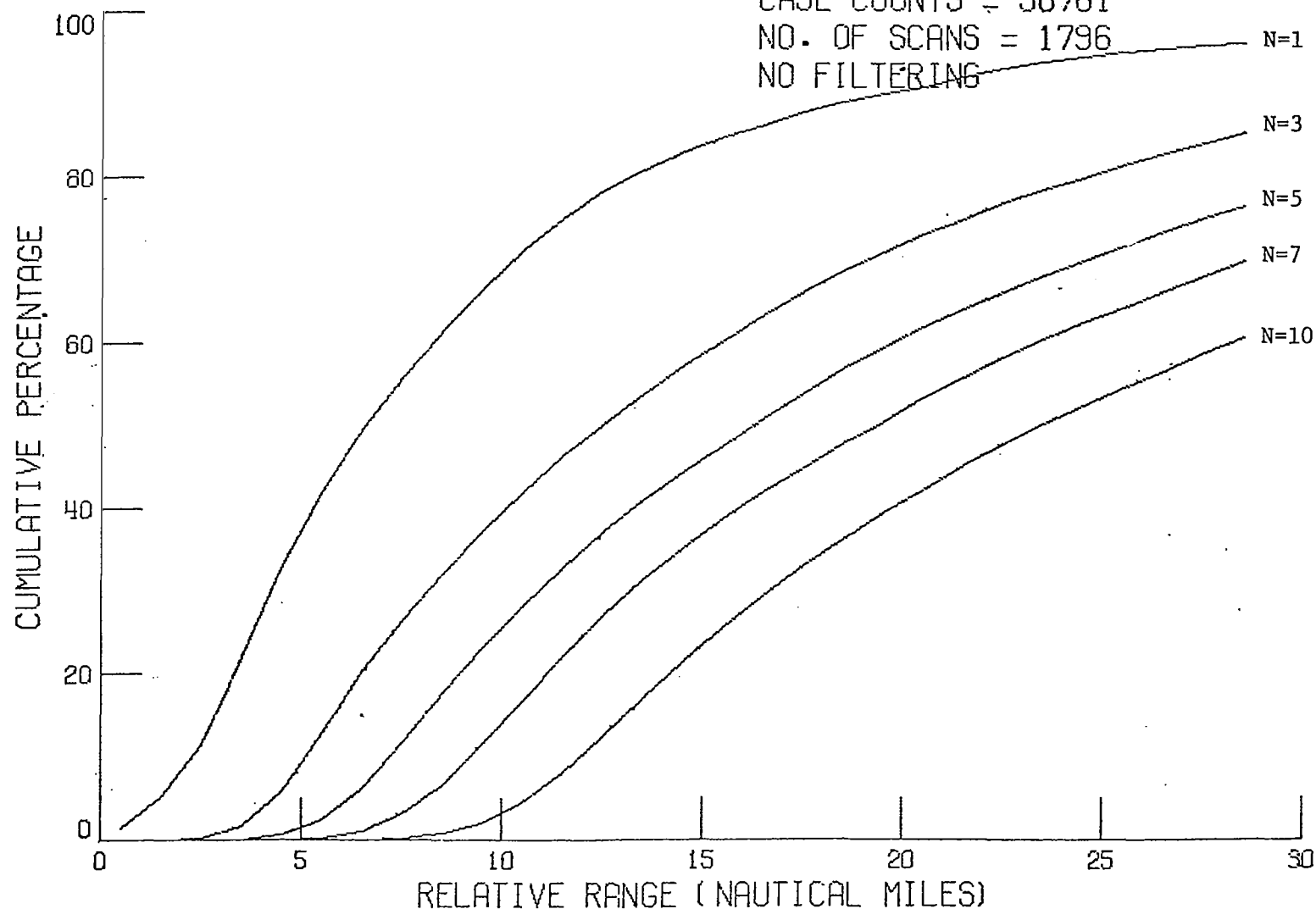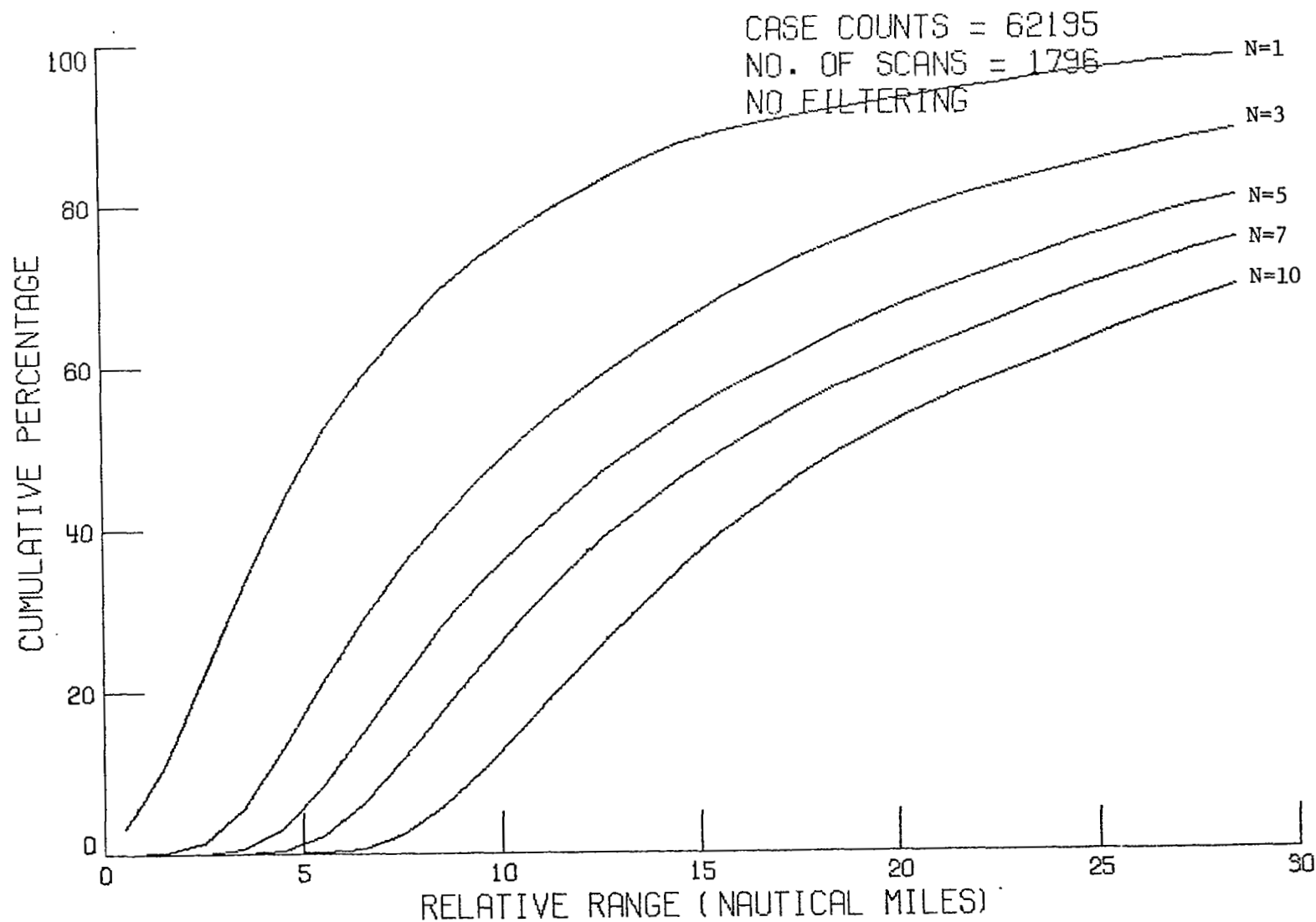is used. Atlanta #2 data.

Figure 7.7 Average percent of flying time that a randomly selected aircraft will have N other aircraft simultaneously displayed within a range value given along the horizontal axis. No discrimination is used. Miami #1 data.
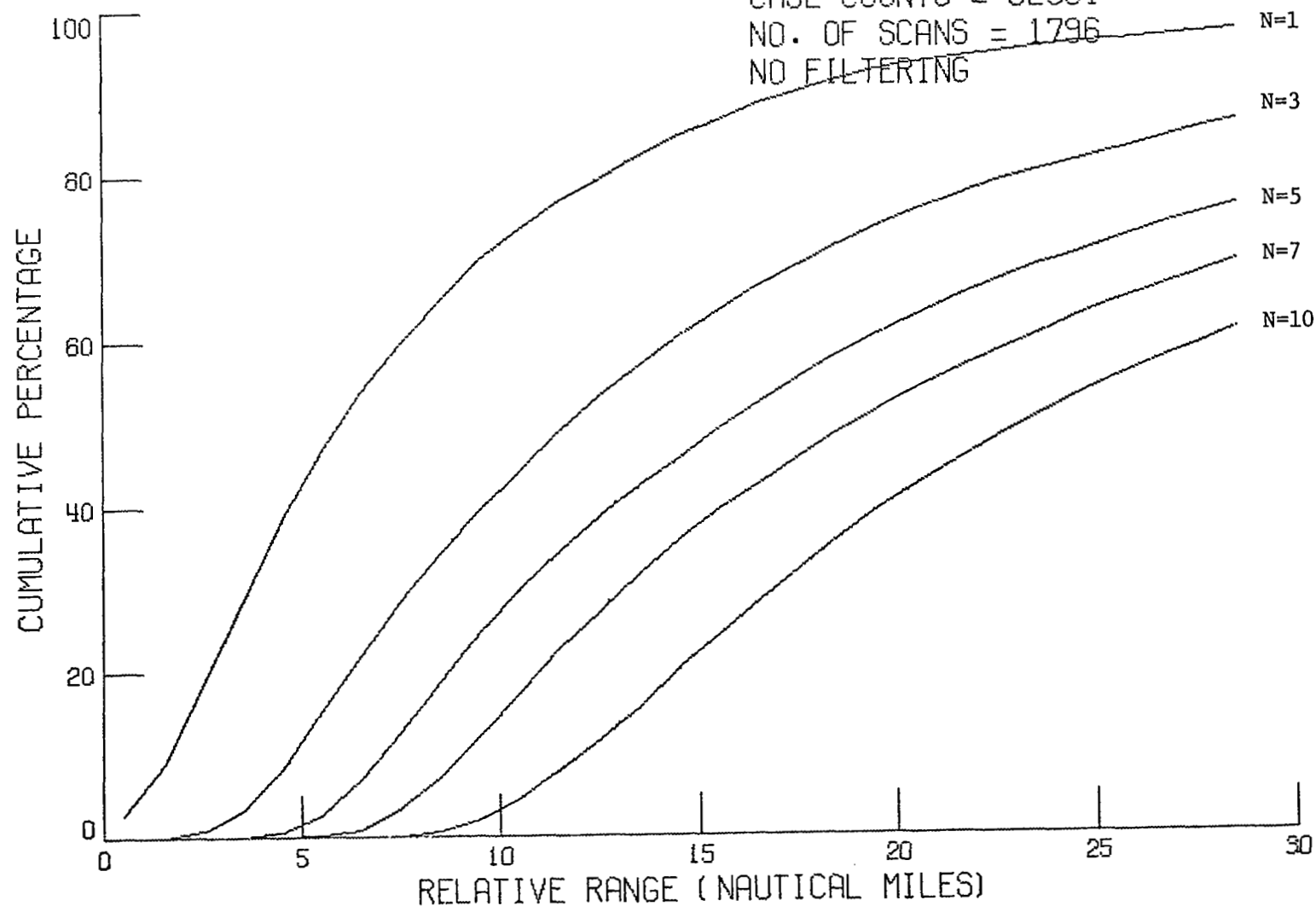
Figure 7.8 Average percent of flying time that a randomly selected aircraft will have N other aircraft simultaneously displayed within a range value given along the horizontal axis. No discrimination is used. Miami #2 data.
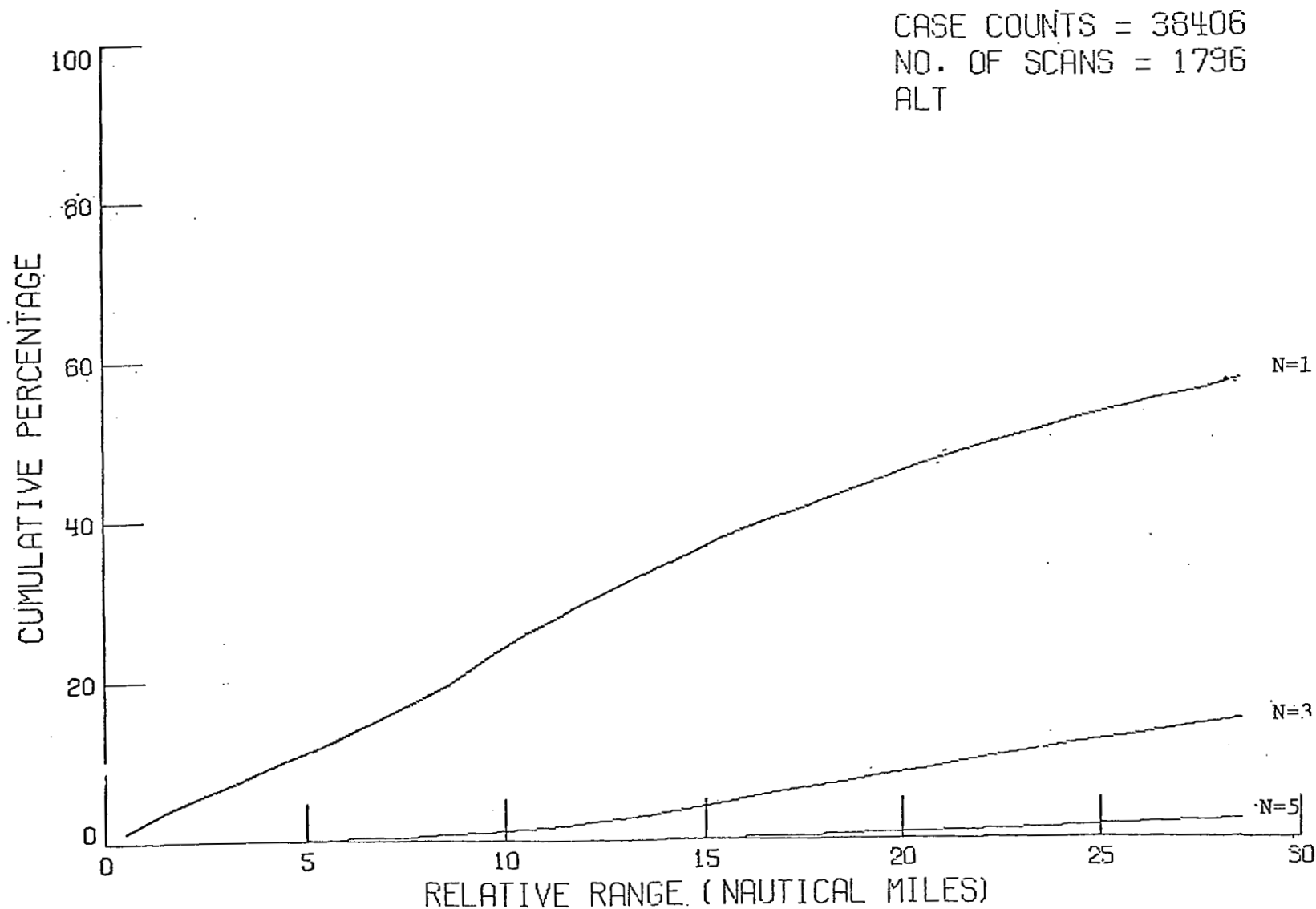
Figure 7.9 Average percent of flying time that a randomly selected aircraft will have N other aircraft displayed simultaneously within a range value along the horizontal axis. Altitude discrimination of ± 1,000 feet. Atlanta #1 data.
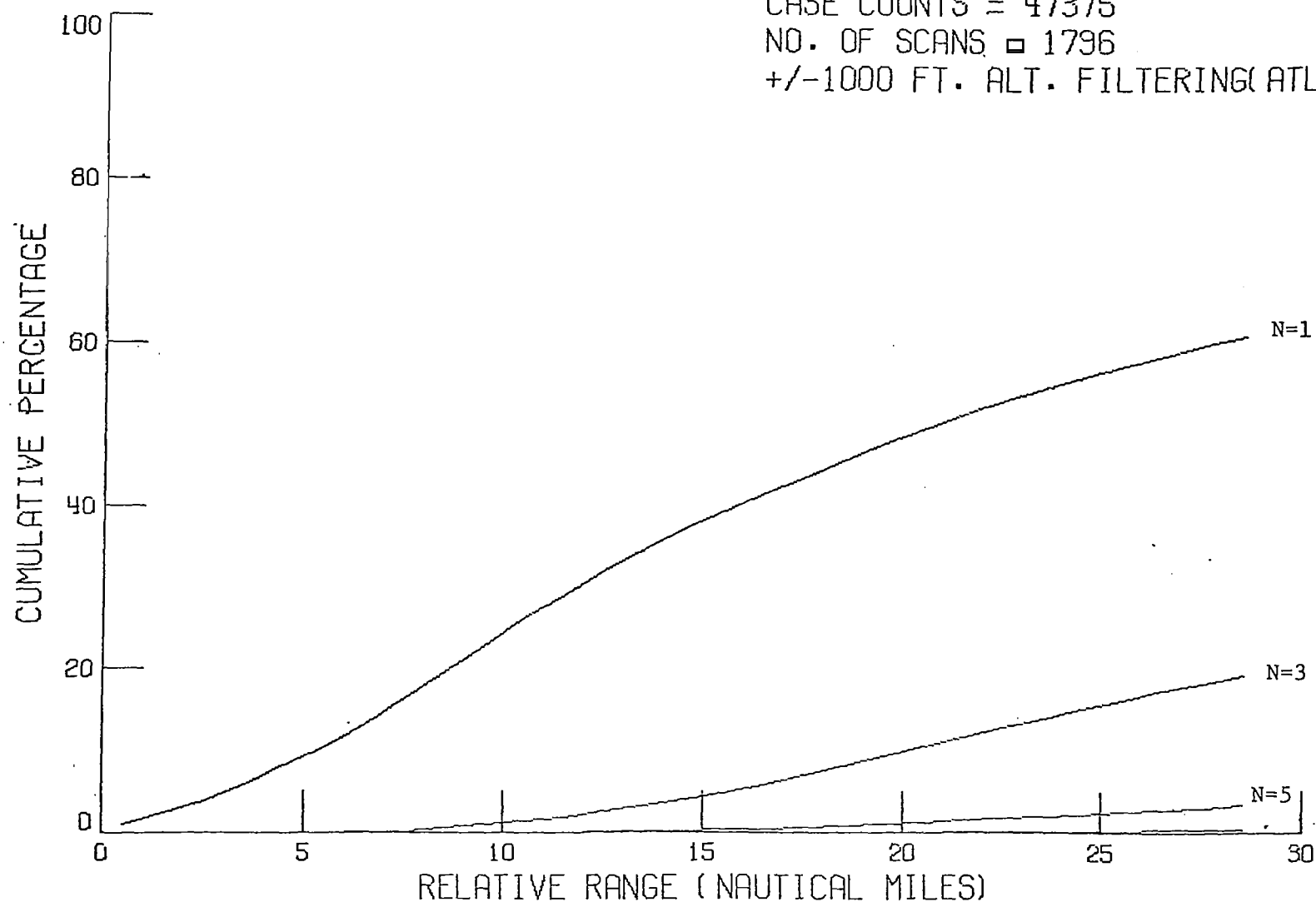
Figure 7.10   Average percent of flying time that a randomly selected aircraft will have N other aircraft displayed simultaneously within a range value along the horizontal axis. Altitude discrimination of ± 1,000 feet. Atlanta #2 data.

CASE COUNTS = 53410
NO. OF SCANS = 1796
+/-1000 F.T. ALT. FILTERING(MIA1)
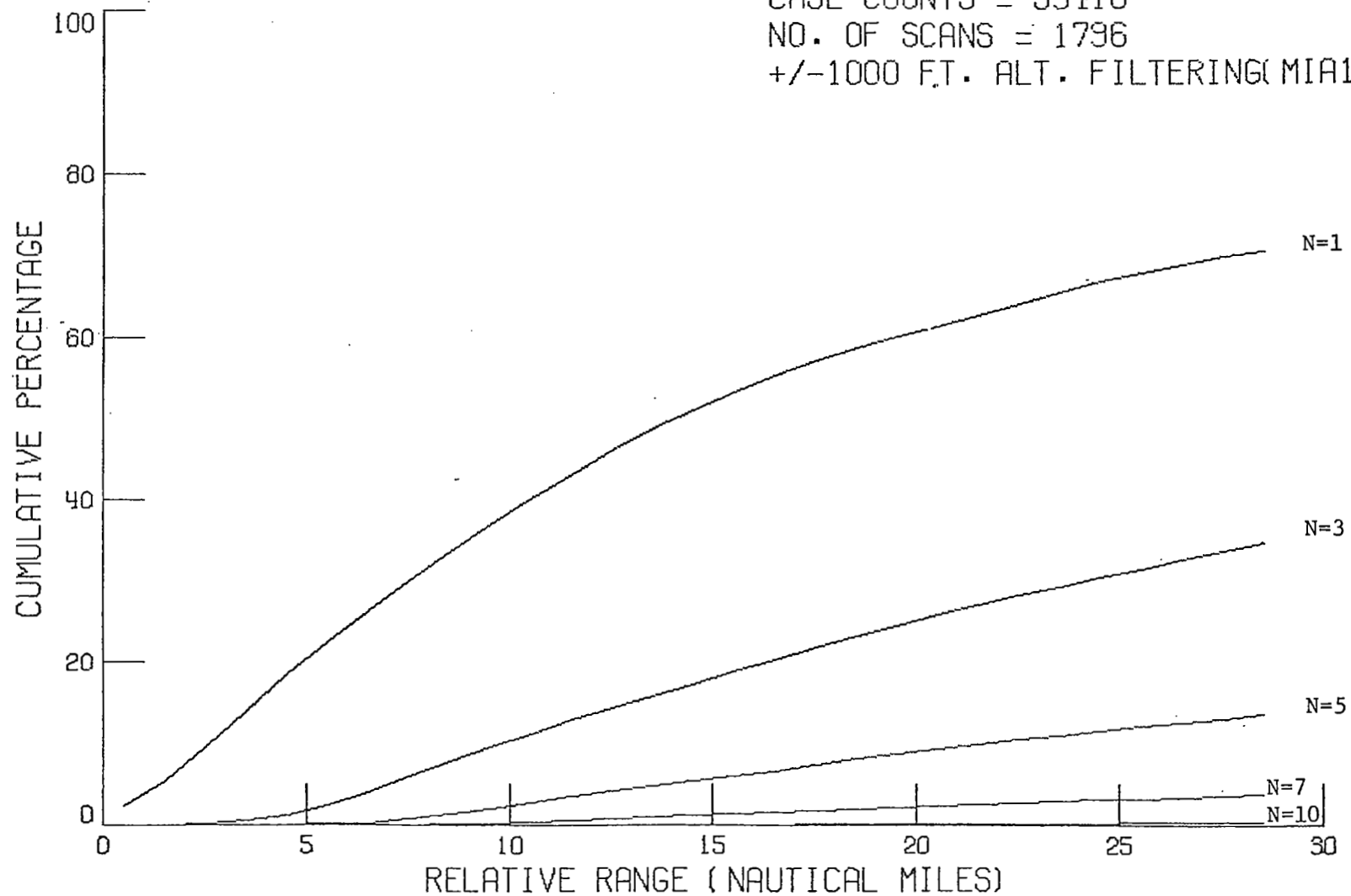
Figure 7.11   Average percent of flying time that a randomly selected aircraft will have N other aircraft simultaneously displayed within a range value given along the horizontal axis. Altitude discrimination of ± 1000 feet. Miami #1 data.

CASE COUNTS = 43956
NO. OF SCANS = 1796
+/-1000 FT. ALT. FILTERING(MIA2)

N=1

N=3

N=5

N=7

CUMULATIVE PERCENTAGE

RELATIVE RANGE (NAUTICAL MILES)

Figure   Average percent of flying time that a randomly selected aircraft
7.12   will have N other aircraft simultaneously displayed within a
         range value given along the horizontal axis. Altitude discrimination
         of ± 1000 feet. Miami #2 data.

Figure
7.13

Average percent of flying time that a randomly selected aircraft
will have N other aircraft simultaneously displayed within a
range value given along the horizontal axis. Altitude discrimination
of $\pm$ 2,000 feet.   Atlanta #1 data.

CASE COUNTS = 53593
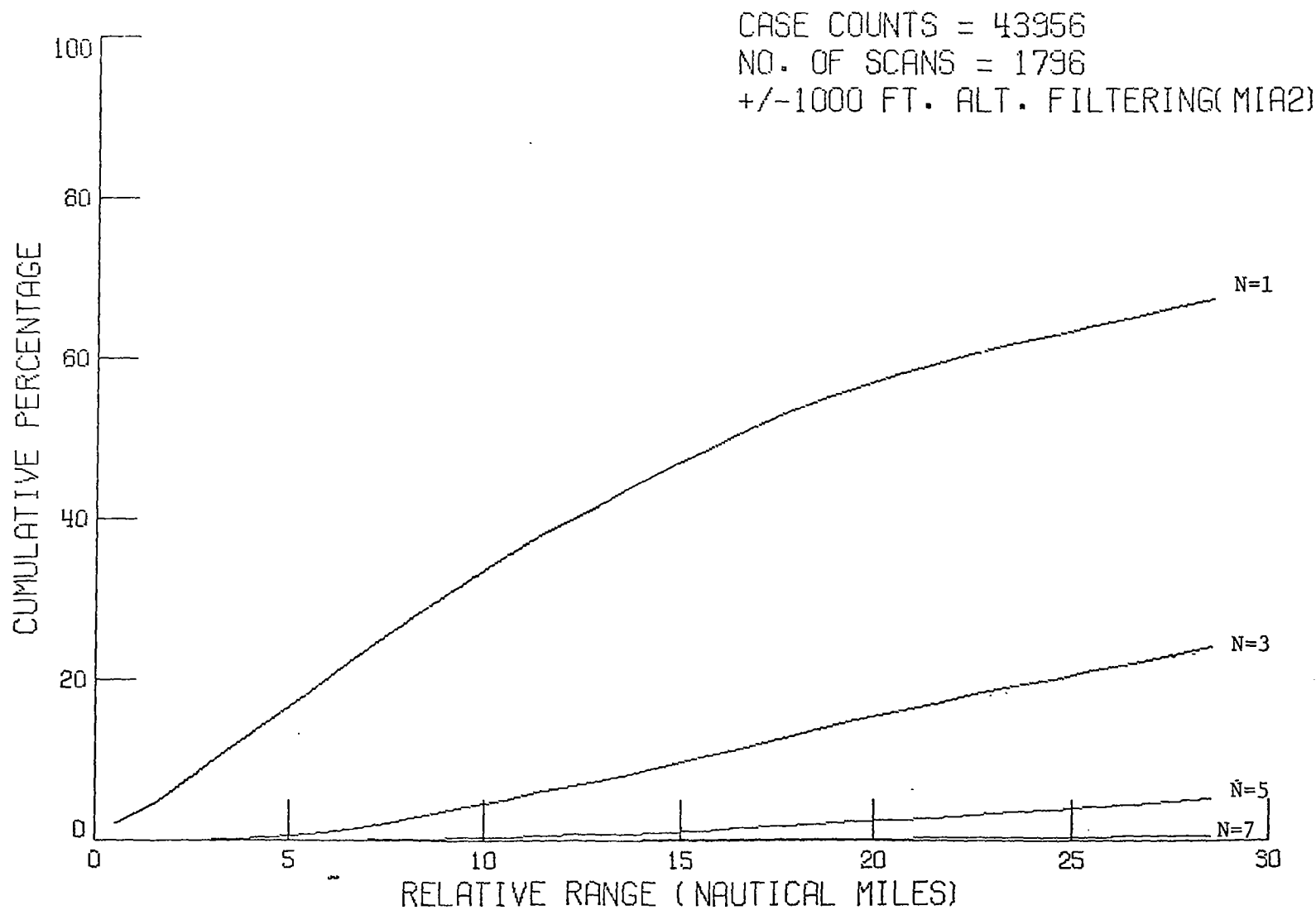NO. OF SCANS = 1796
+/-2000 FT. ALT. FILTERING(ATL2)

N=1

N=3

N=5

N=7

N=10

CUMULATIVE PERCENTAGE

RELATIVE RANGE (NAUTICAL MILES)

Figure   Average percent of flying time that a randomly selected
7.14   aircraft will have N other aircraft simultaneously displayed within
          a range value given along the horizontal axis. Altitude discrimination
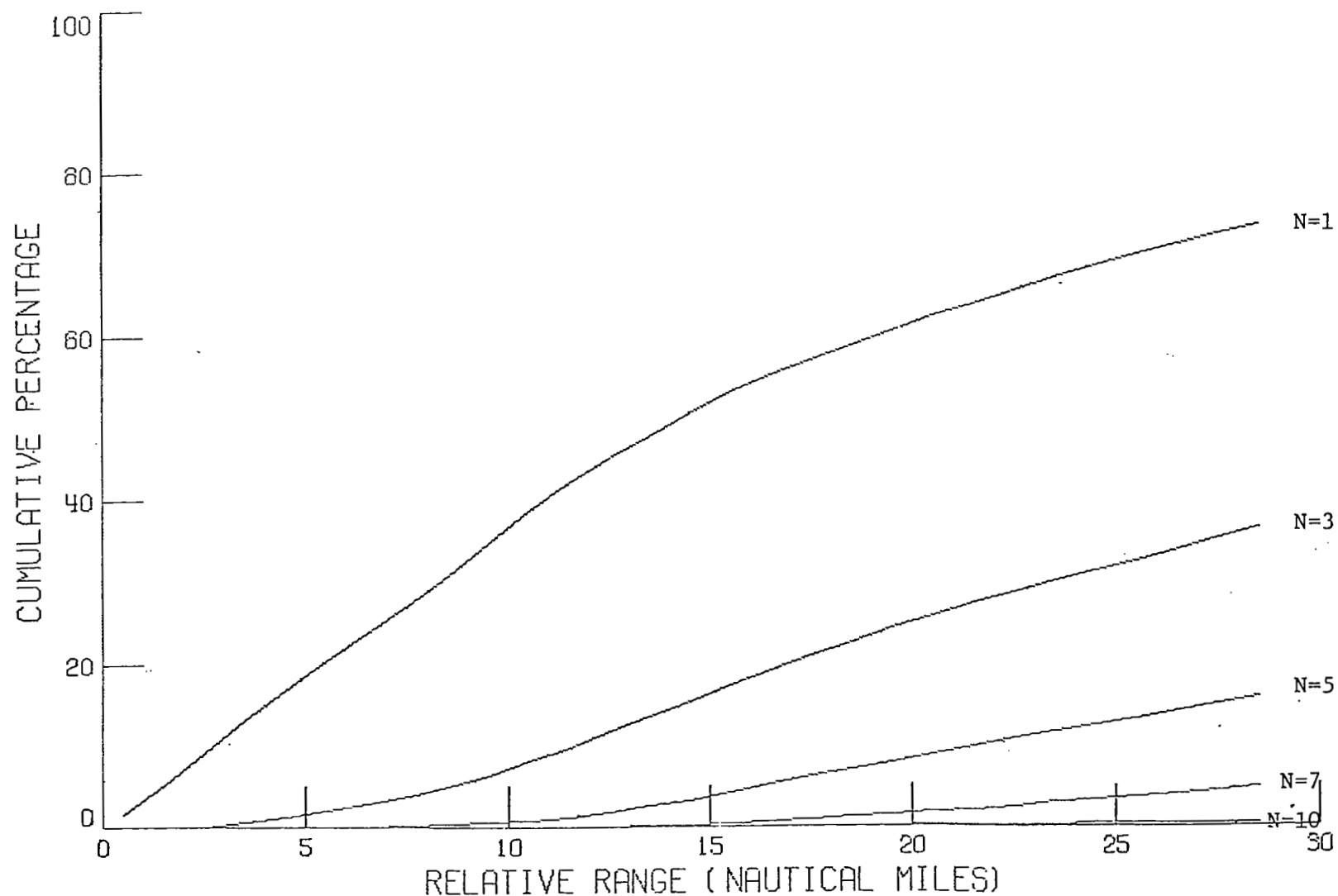   of ± 2,000 feet.   Atlanta #2 data.

Figure 7.15 Average percent of flying time that a randomly selected aircraft will have N other aircraft simultaneously displayed within a range value given along the horizontal axis. Altitude discrimination of ± 2000 feet. Miami #1 data.
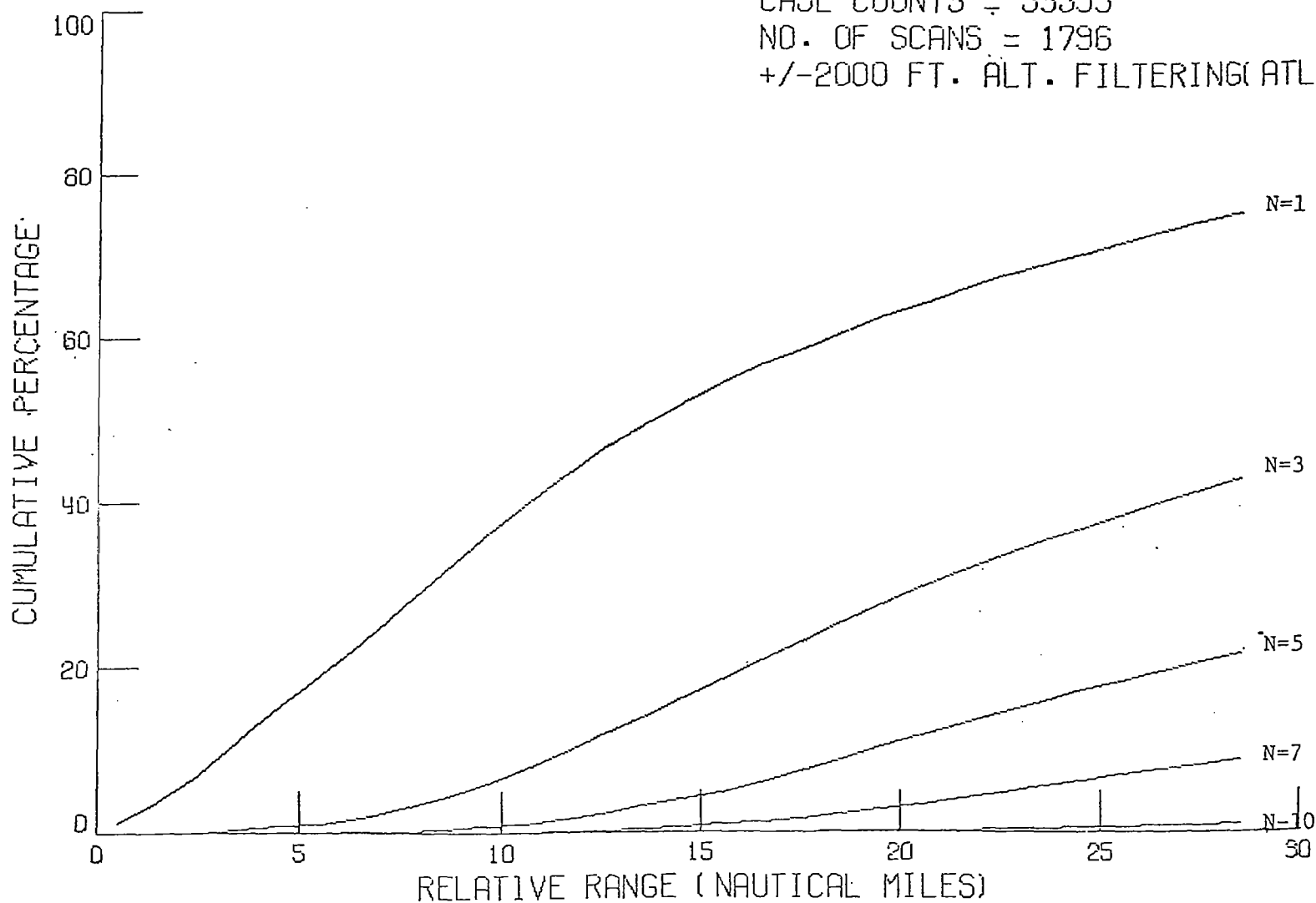
Figure
7.16

Average percent of flying time that a randomly selected aircraft
will have N other aircraft simultaneously displayed within a
range value given along the horizontal axis. Altitude discrimination
of ± 2000 feet. Miami #2 data.
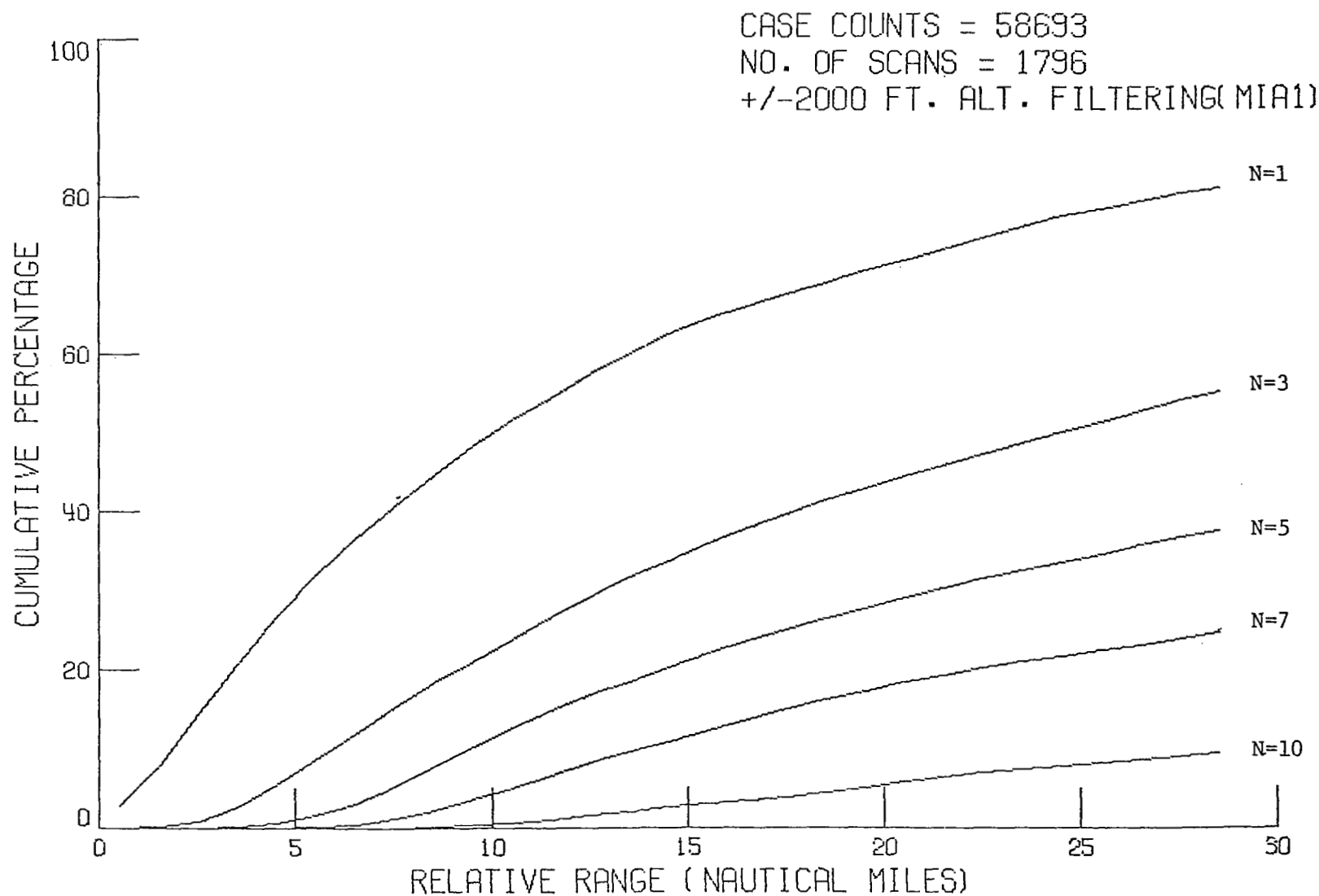
Figure 7.17   Average percent of flying time that a randomly selected aircraft
                will have N other aircraft simultaneously displayed within a
                range value given along the horizontal axis.   Altitude discrimination
                of ± 2500 feet.   Atlanta #1 data.

CASE COUNTS = 48781
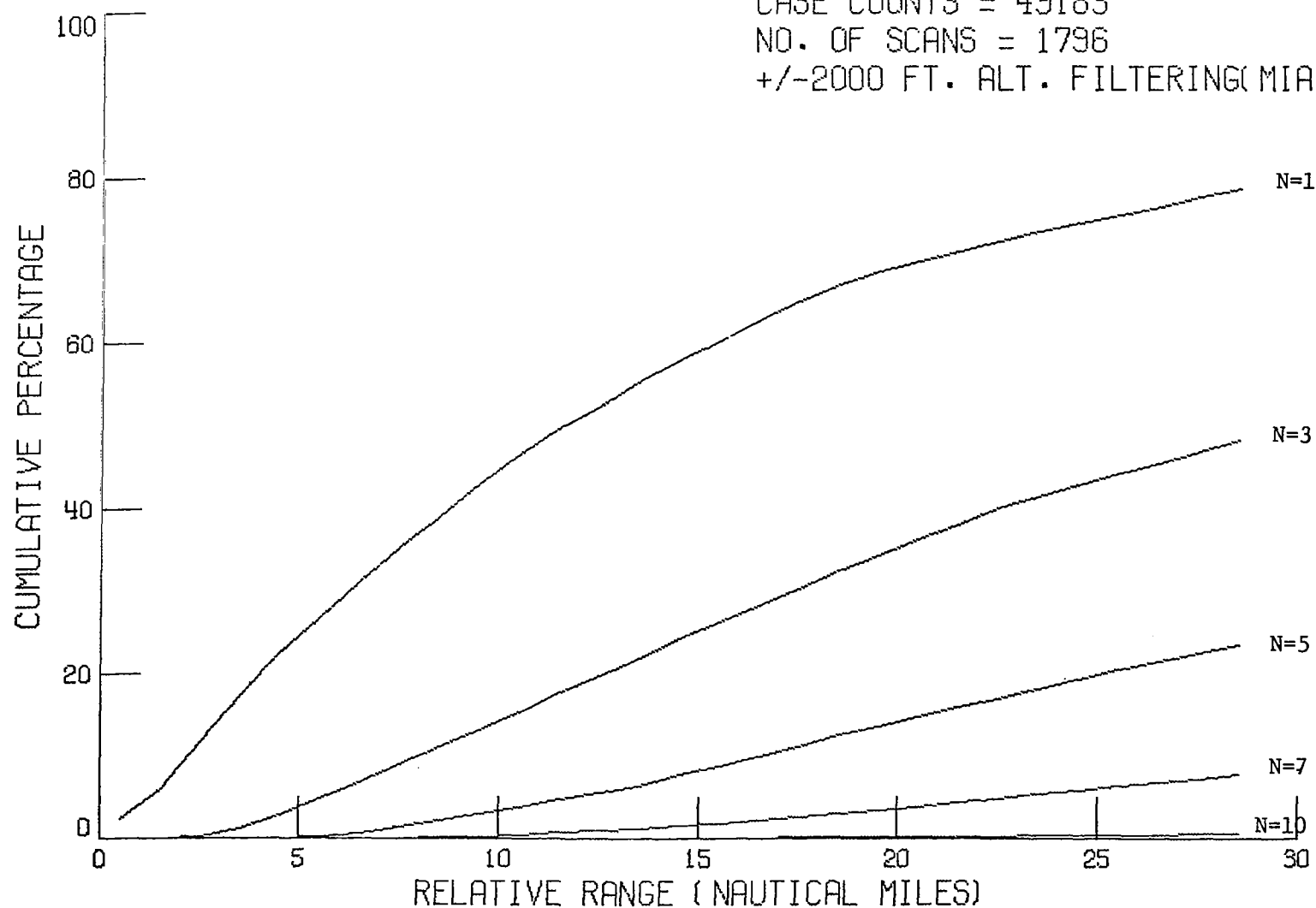NO. OF SCANS = 1796
CLOSING VEL. FILTERING (VC>0)

Figure 7.18   Average percent of flying time that a randomly selected aircraft
will have N other aircraft simultaneously displayed within a range
value given along the horizontal axle. Closing velocity discrimination
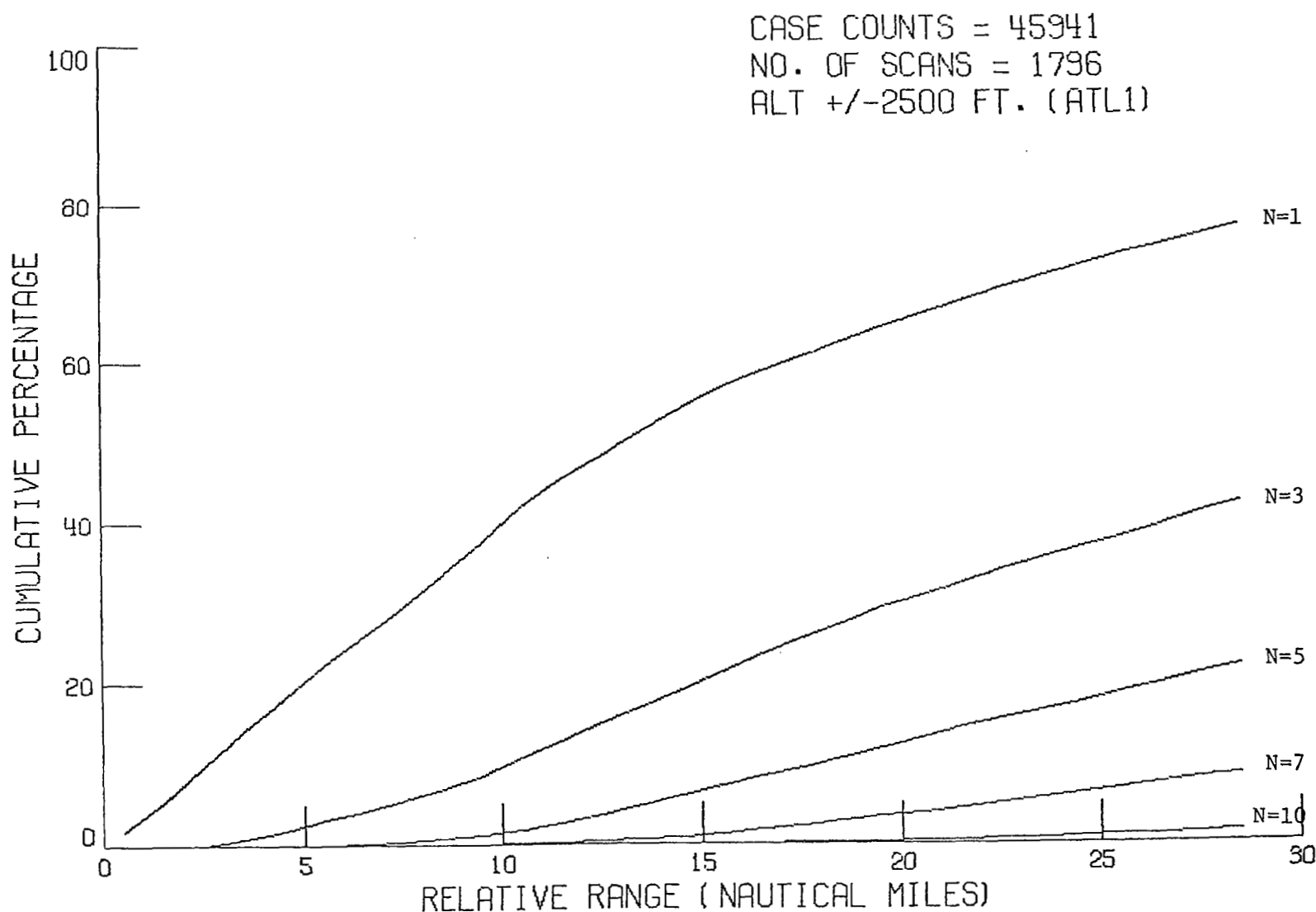$(V_c > 0)$. Atlanta #1 data.

Figure
7.19

Average percent of flying time that a randomly selected aircraft will have N other aircraft simultaneously displayed within a range value given along the horizontal axis. Closing velocity discrimination ($V_c > 0$). Atlanta #2 data.

CASE COUNTS = 61863
NO. OF SCANS = 1796
VC>0 FILTERING (MIA1)

N=1
N=3
N=5
N=7
N=10

CUMULATIVE PERCENTAGE

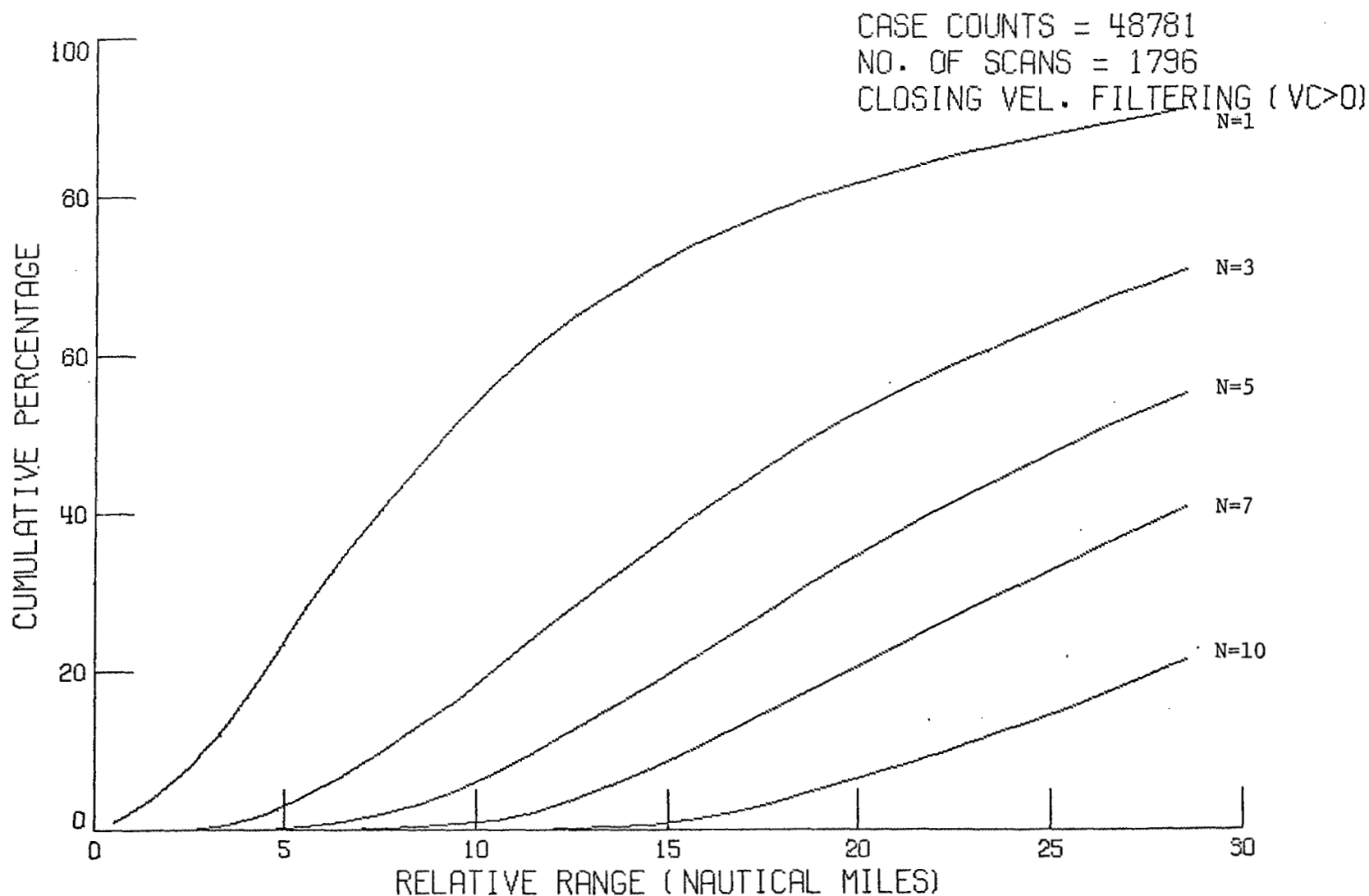RELATIVE RANGE (NAUTICAL MILES)

Figure 7.20 Average percent of flying time that a randomly selected aircraft will have N other aircraft simultaneously displayed within a range value given along the horizontal axis. Closing velocity discrimination $(V_c > 0)$. Miami #1 data.

CASE COUNTS = 52638
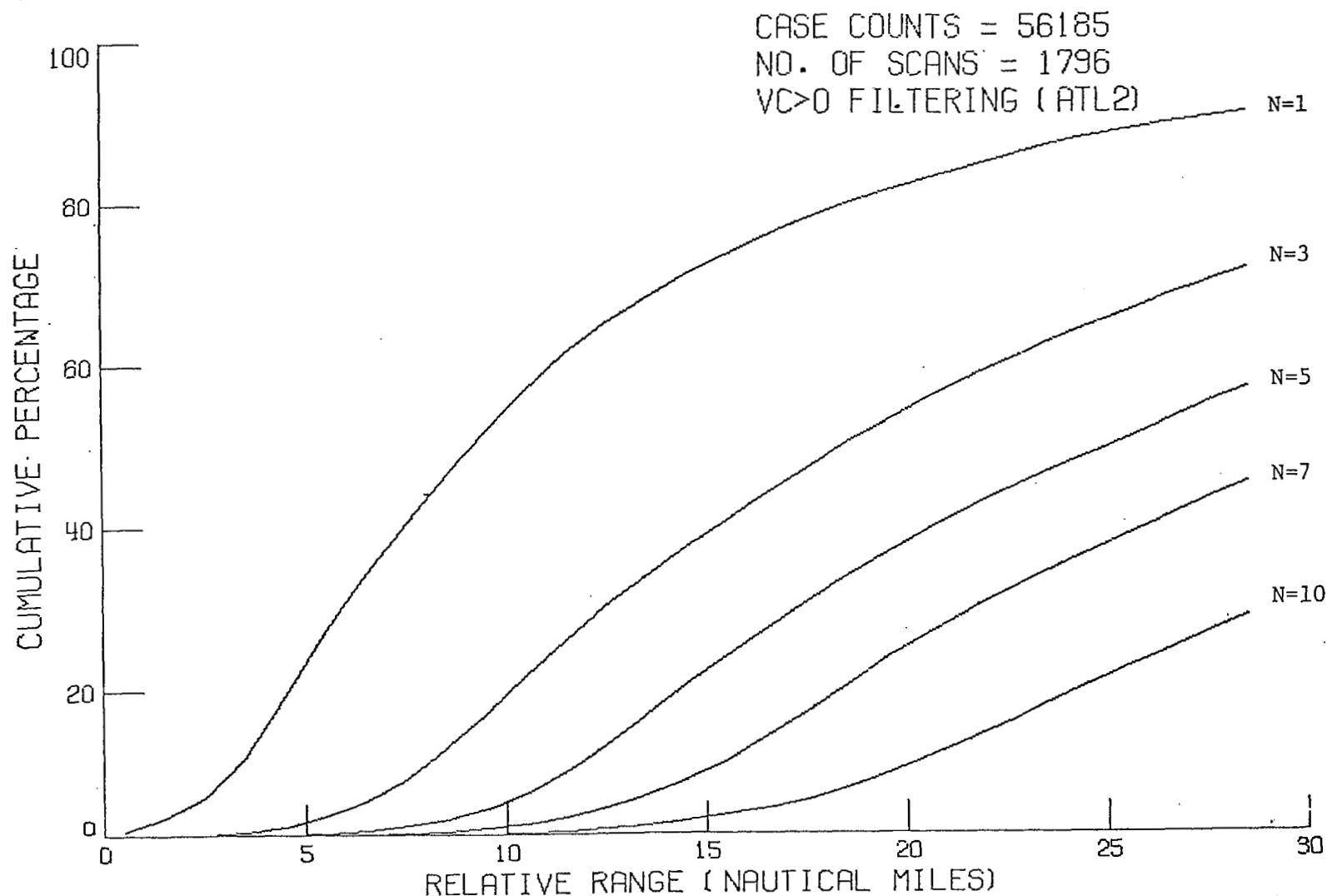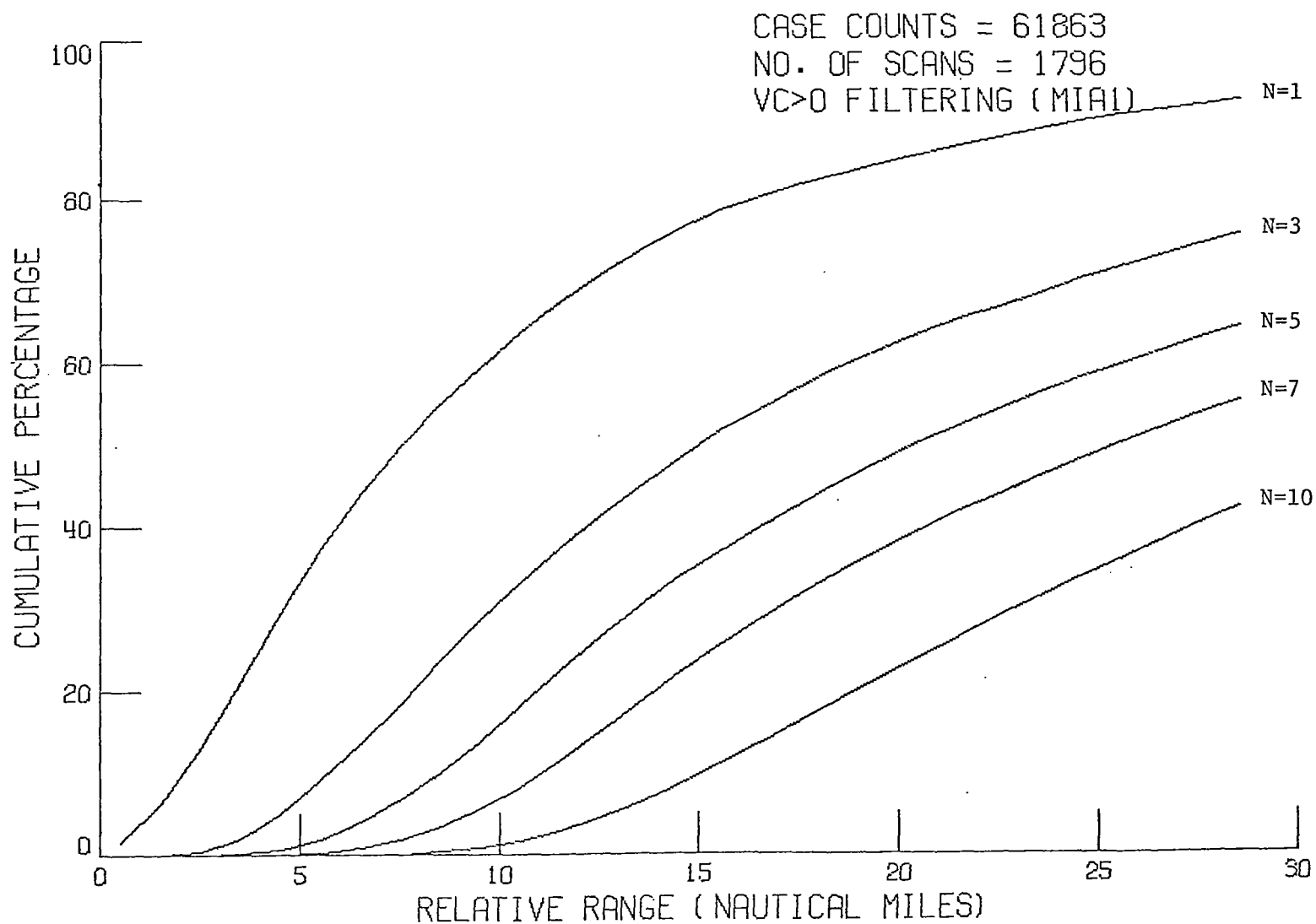NO. OF SCANS = 1796
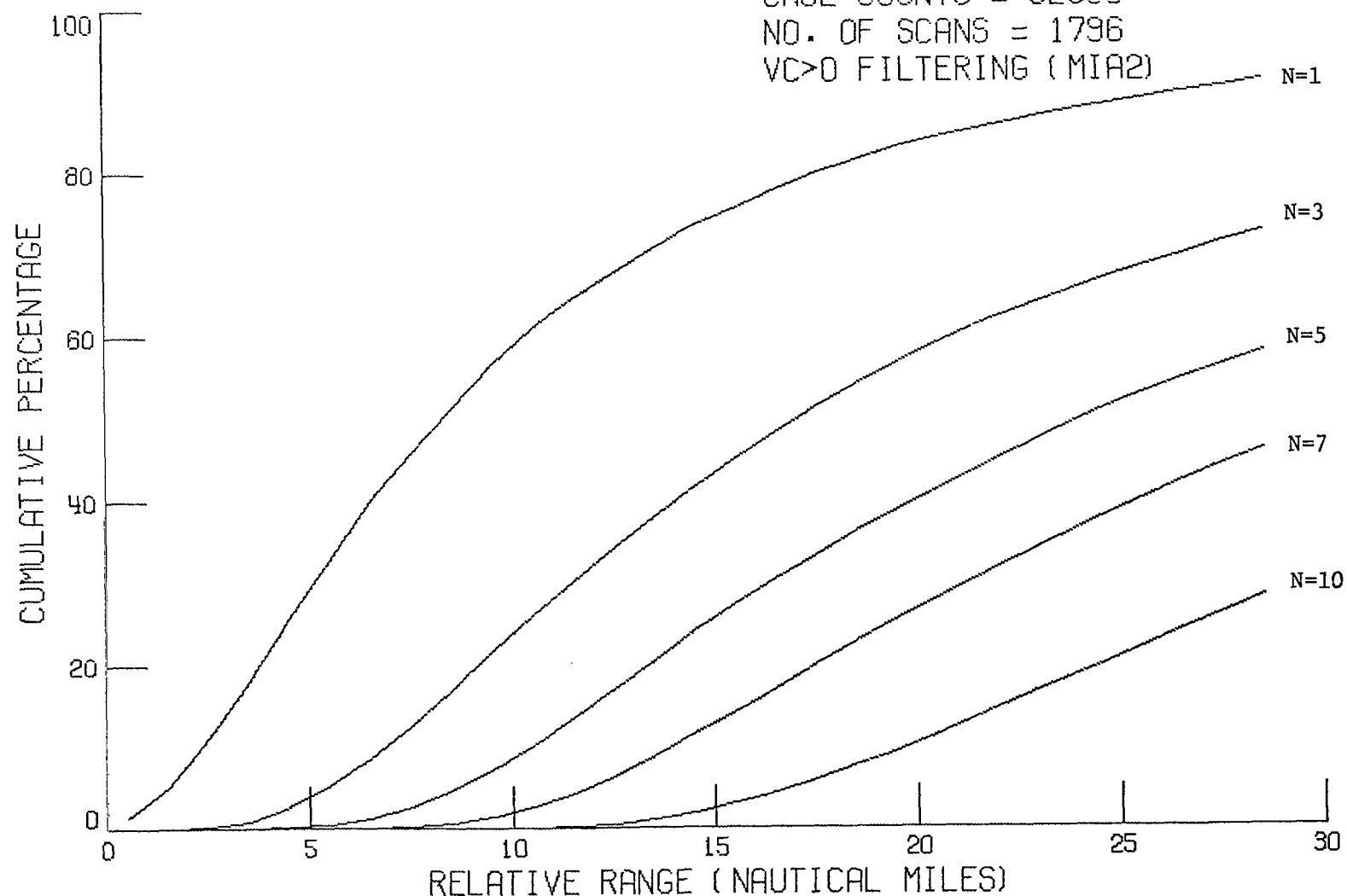VC>0 FILTERING (MIA2)

Figure 7.21   Average Percent of flying time that a randomly selected aircraft will have N other aircraft simultaneously displayed within a range value given along the horizontal axis. Closing velocity discrimination $(V_c > 0)$. Miami #2 data.

CASE COUNTS = 48781
NO. OF SCANS = 1796
NO FILTERING

Figure 7.22 Average percentage of flying time that a randomly selected
aircraft will simultaneously observe N other aircraft with
a value of the Tau parameter less than the value given along
the horizontal axis. No other discrimination is used.
Atlanta #1 data.

Figure 7.23 Average percentage of flying time that a randomly selected aircraft will simultaneously observe N other aircraft with a value of the Tau parameter less than the value given along the horizontal axis. No other discrimination is used. Atlanta #2 data.
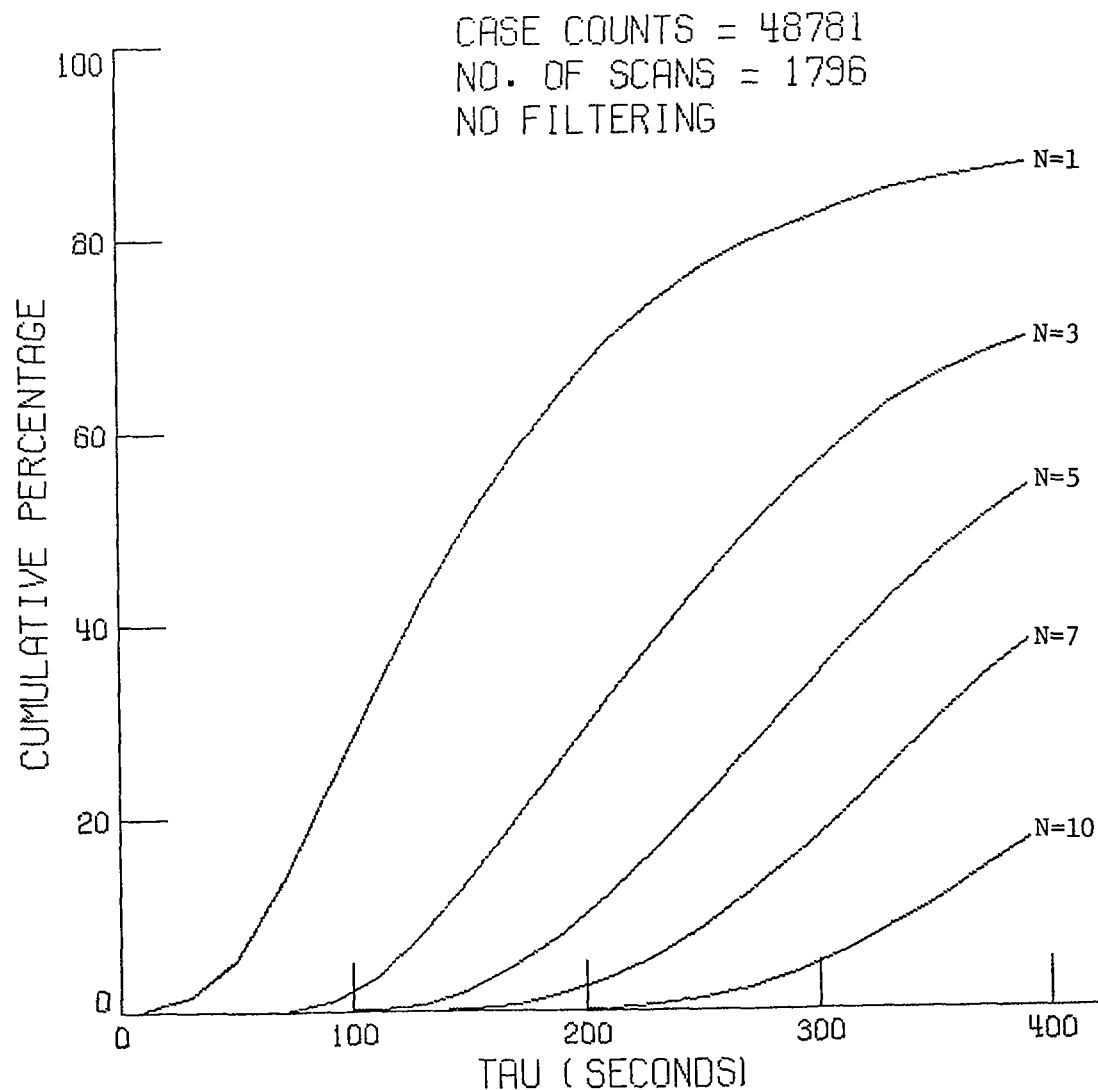
Figure 7.24 Average percentage of flying time that a randomly selected
aircraft will simultaneously observe N other aircraft with
a value of the Tau parameter less than the value given along
the horizontal axis. No other discrimination is used.
Miami #1 data.

CASE COUNTS = 52638
NO. OF SCANS = 1796
NO FILTERING

N=1

N=3

N=5

N=7

N=10

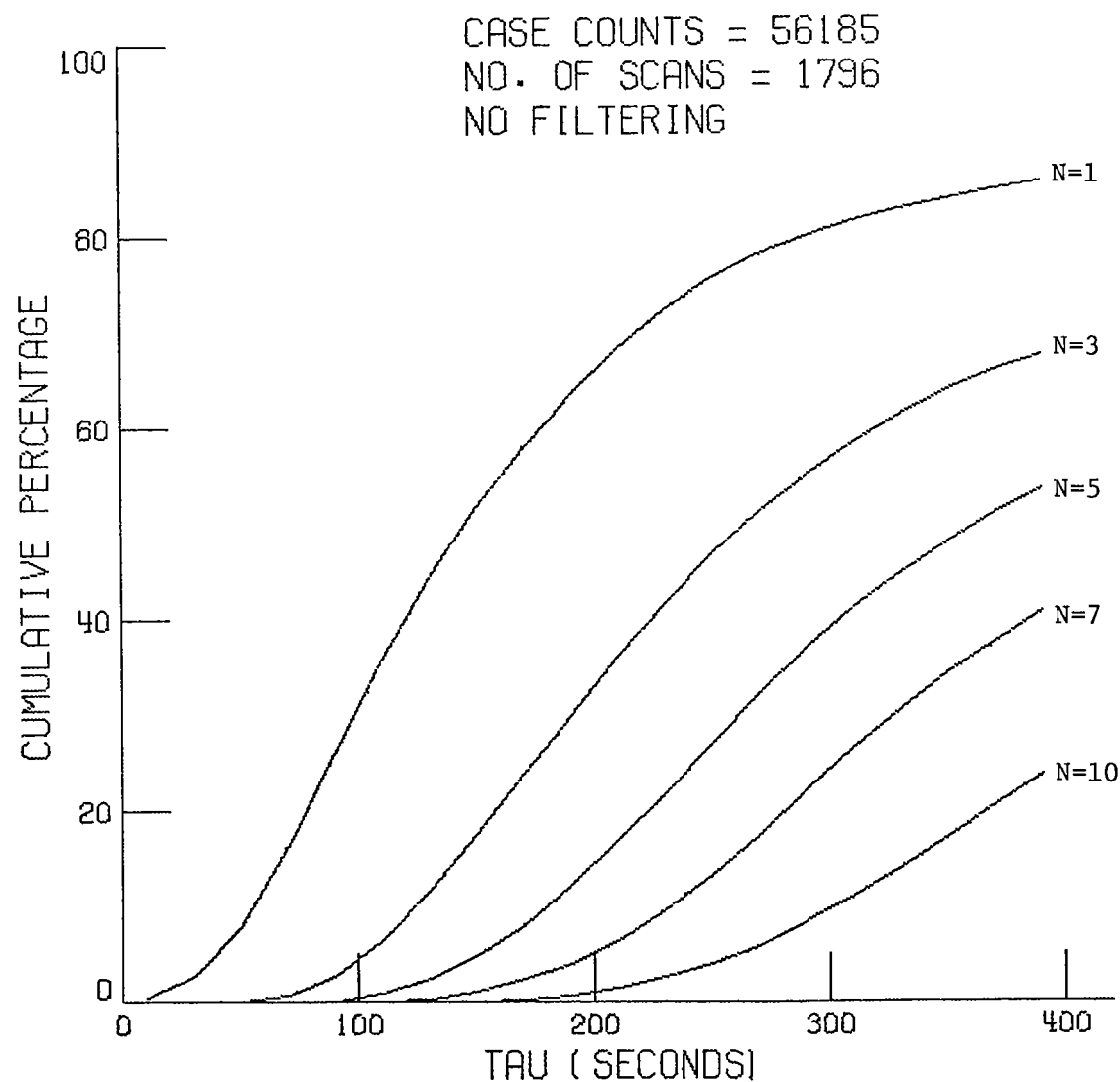CUMULATIVE PERCENTAGE

TAU (SECONDS)

Figure 7.25 Average percentage of flying time that a randomly selected
aircraft will simultaneously observe N other aircraft with
a value of the Tau parameter less than the value given along
the horizontal axis. No other discrimination is used.
Miami #2 data.

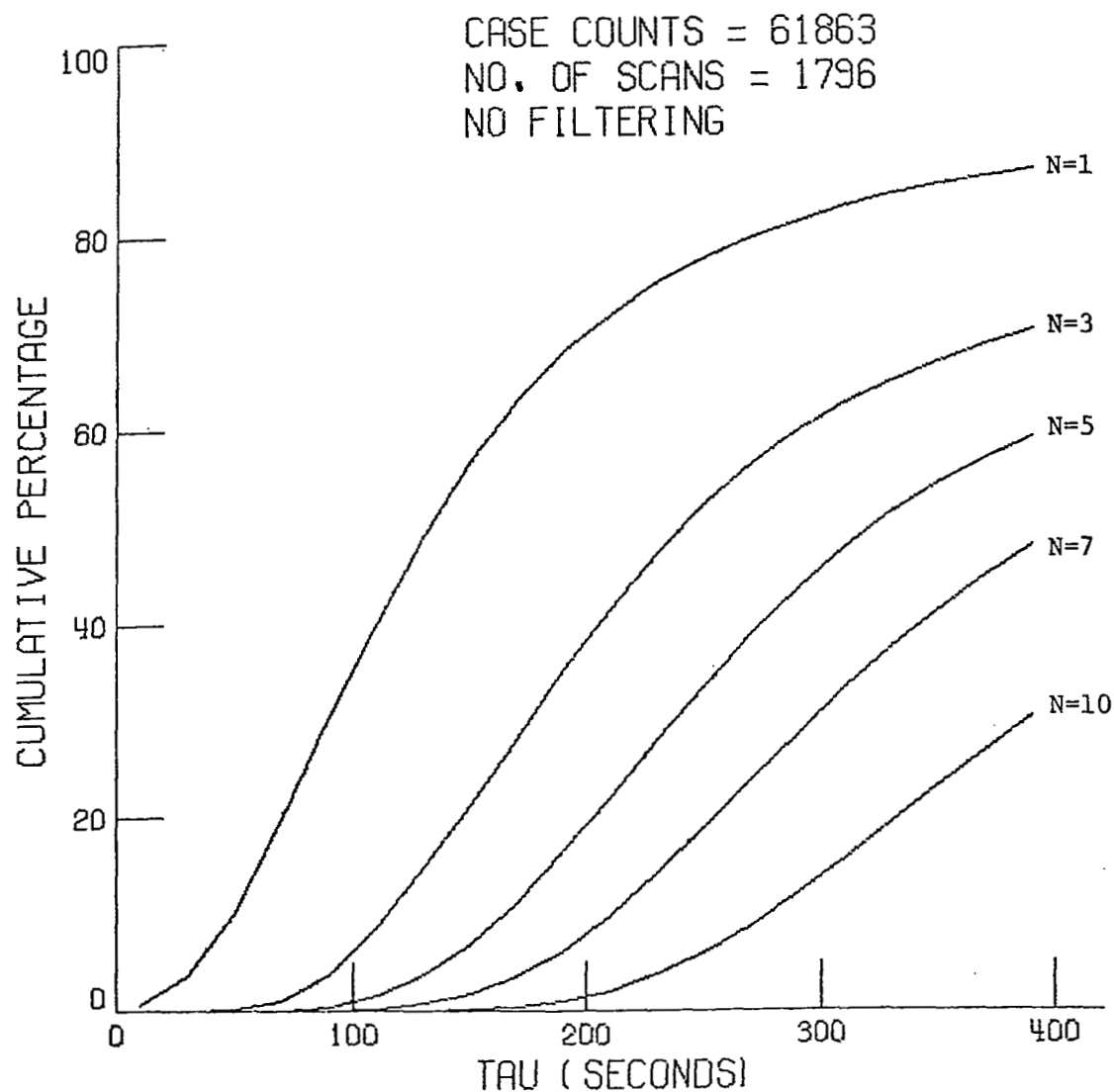Figure 7.26 Average percent of flying time that a randomly selected aircraft
will simultaneously observe N other aircraft with a value of the
Tau parameter less than the value given along the horizontal axis.
Altitude discrimination of ± 2000 feet. Atlanta #1 data.

CASE COUNTS = 46321
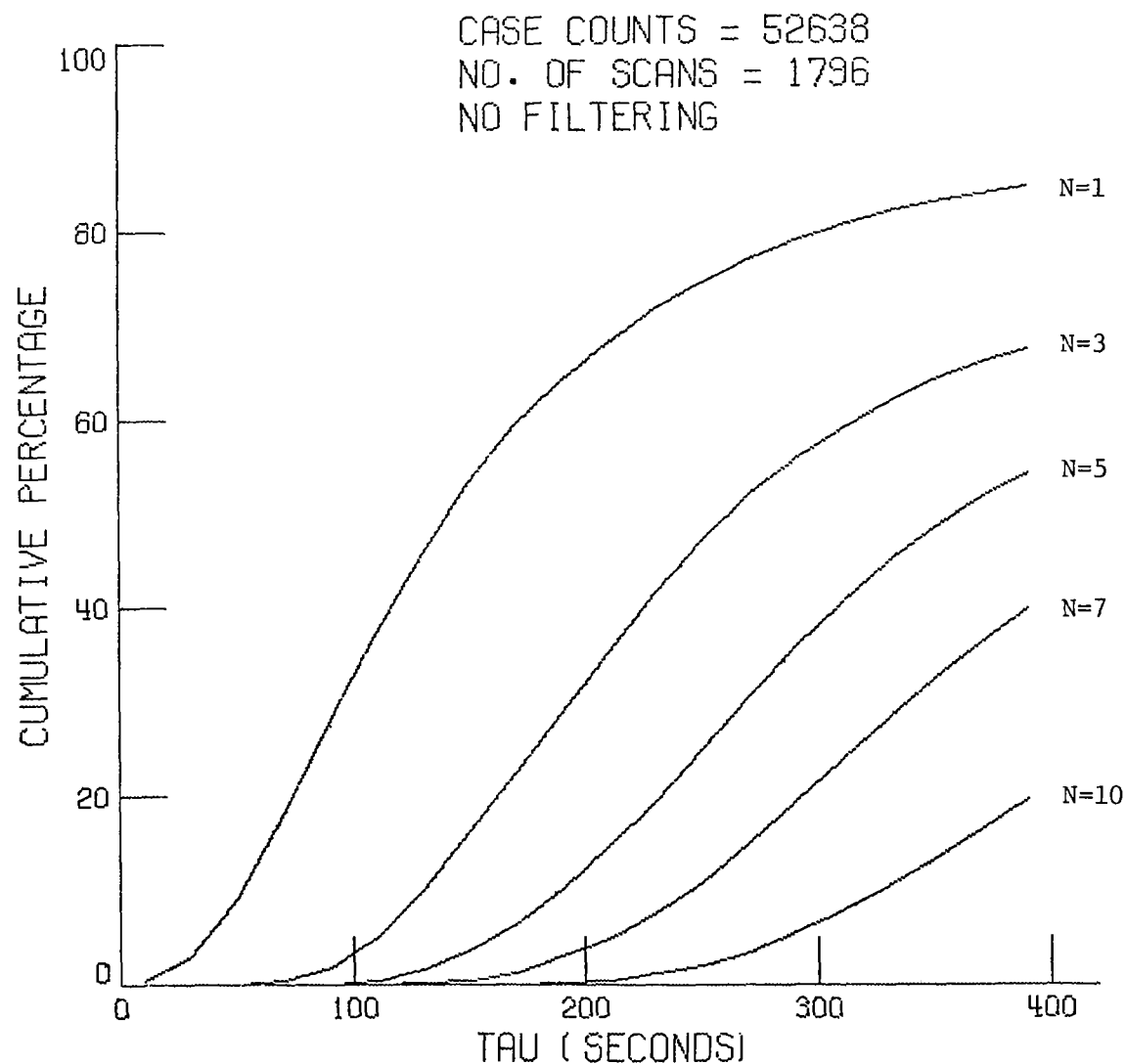NO. OF SCANS = 1796
+/-2000 FT. ALT. FILTERING(ATL2)

Figure 7.27 Average percent of flying time that a randomly selected aircraft
will simultaneously observe N other aircraft with a value of the
Tau parameter less than the value given along the horizontal axis.
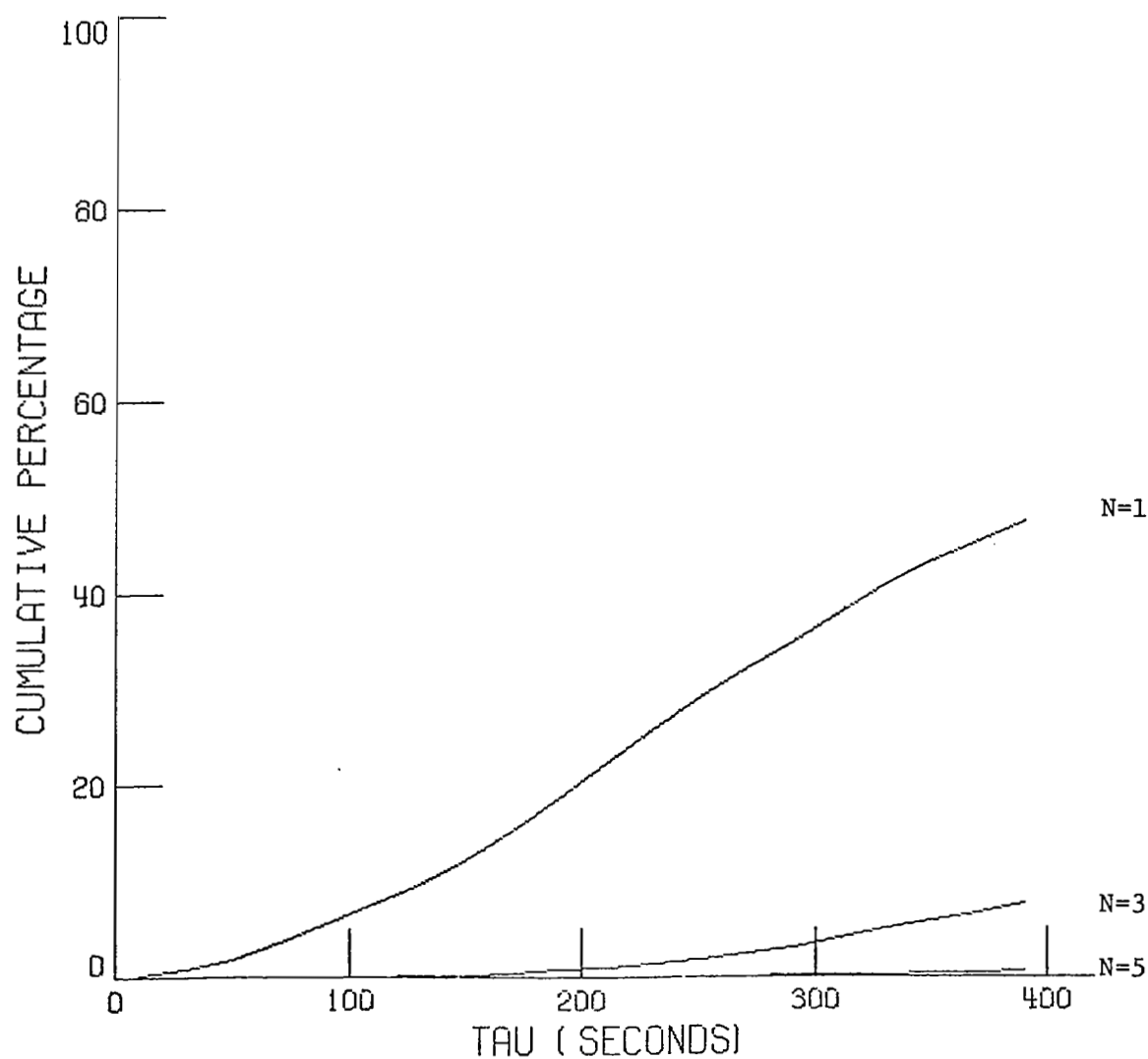Altitude discrimination of ± 2000 feet. Atlanta #2 data.

Figure 7.28 Average percent of flying time that a randomly selected aircraft
will simultaneously observe N other aircraft with a value of the
Tau parameter less than the value given along the horizontal axis.
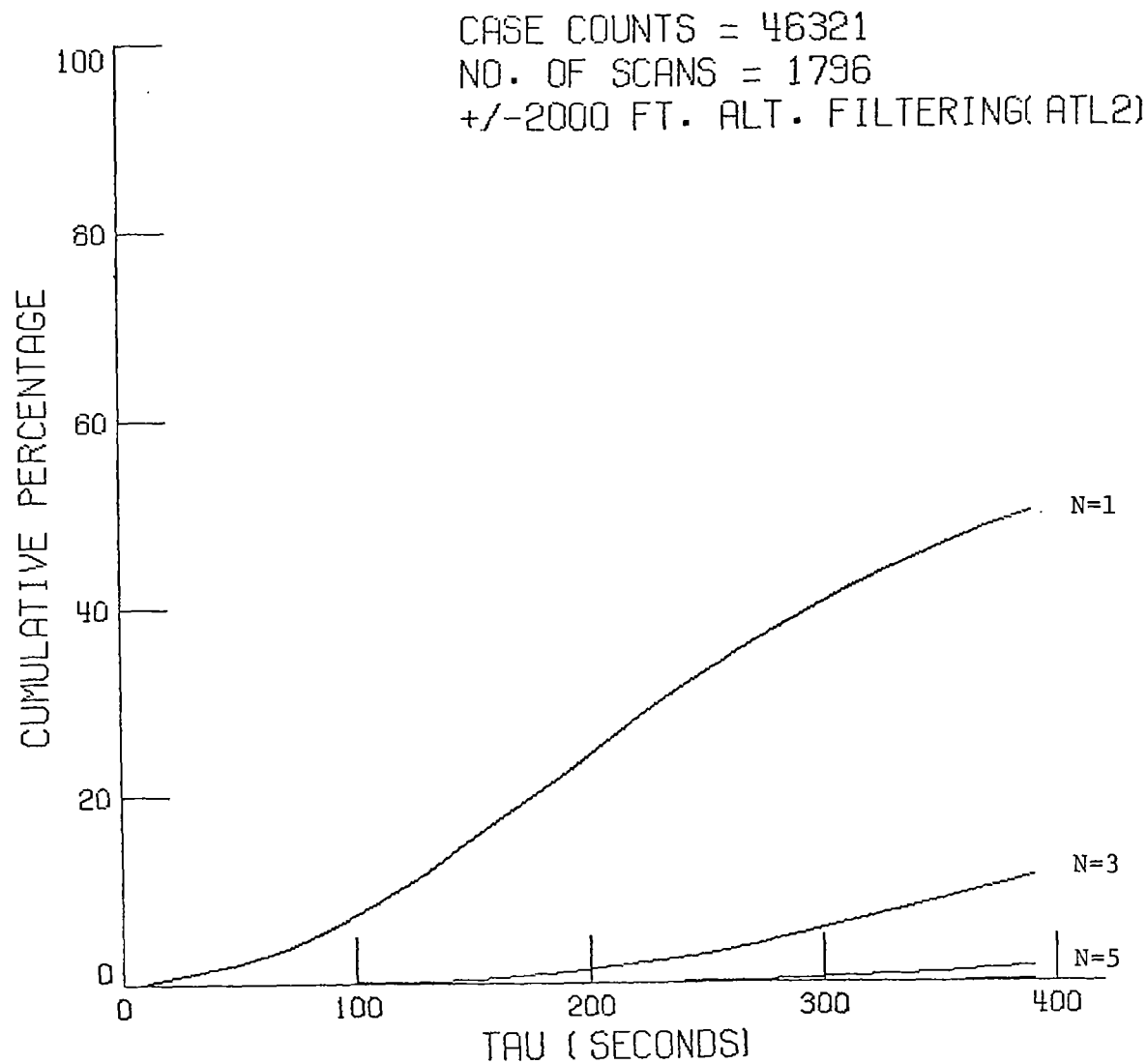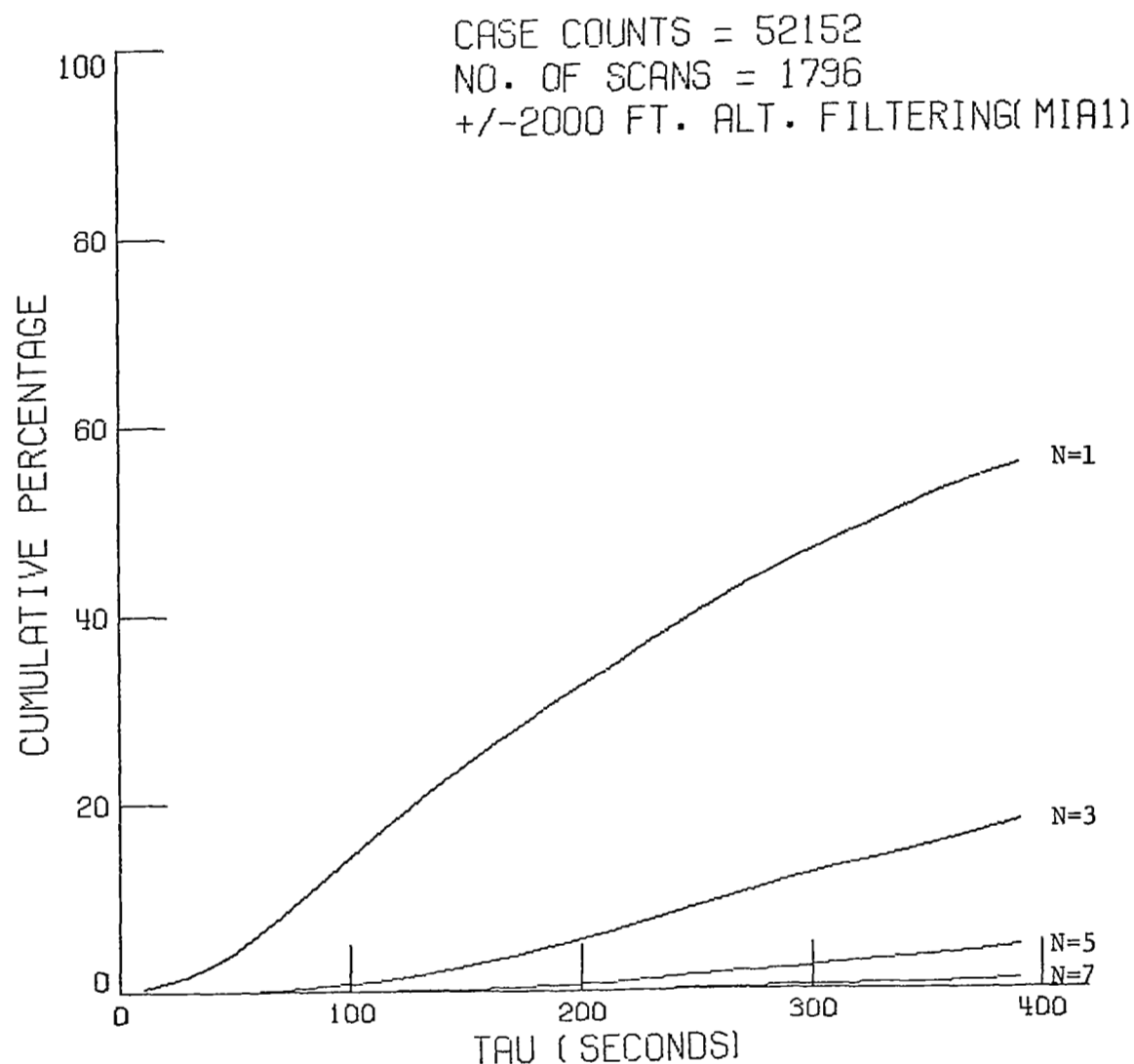Altitude discrimination of ± 2000 feet. Miami #1 data.

Figure 7.29   Average percent of flying time that a randomly selected aircraft
will simultaneously observe N other aircraft with a value of the
Tau parameter less than the value given along the horizontal axis.
Altitude discrimination of + 2000 feet.   Miami #2 data.

Figure 7.30 Average percent of flying time that a randomly selected aircraft
will simultaneously observe N other aircraft with a value of the
Modified Tau parameter less than the value given along the horizontal
axis. No other discrimination is used. Atlanta #1 data.

Figure 7.31 Average percent of flying time that a randomly selected aircraft
will simultaneously observe N other aircraft with a value of the
Modified Tau parameter less than the value given along the horizontal
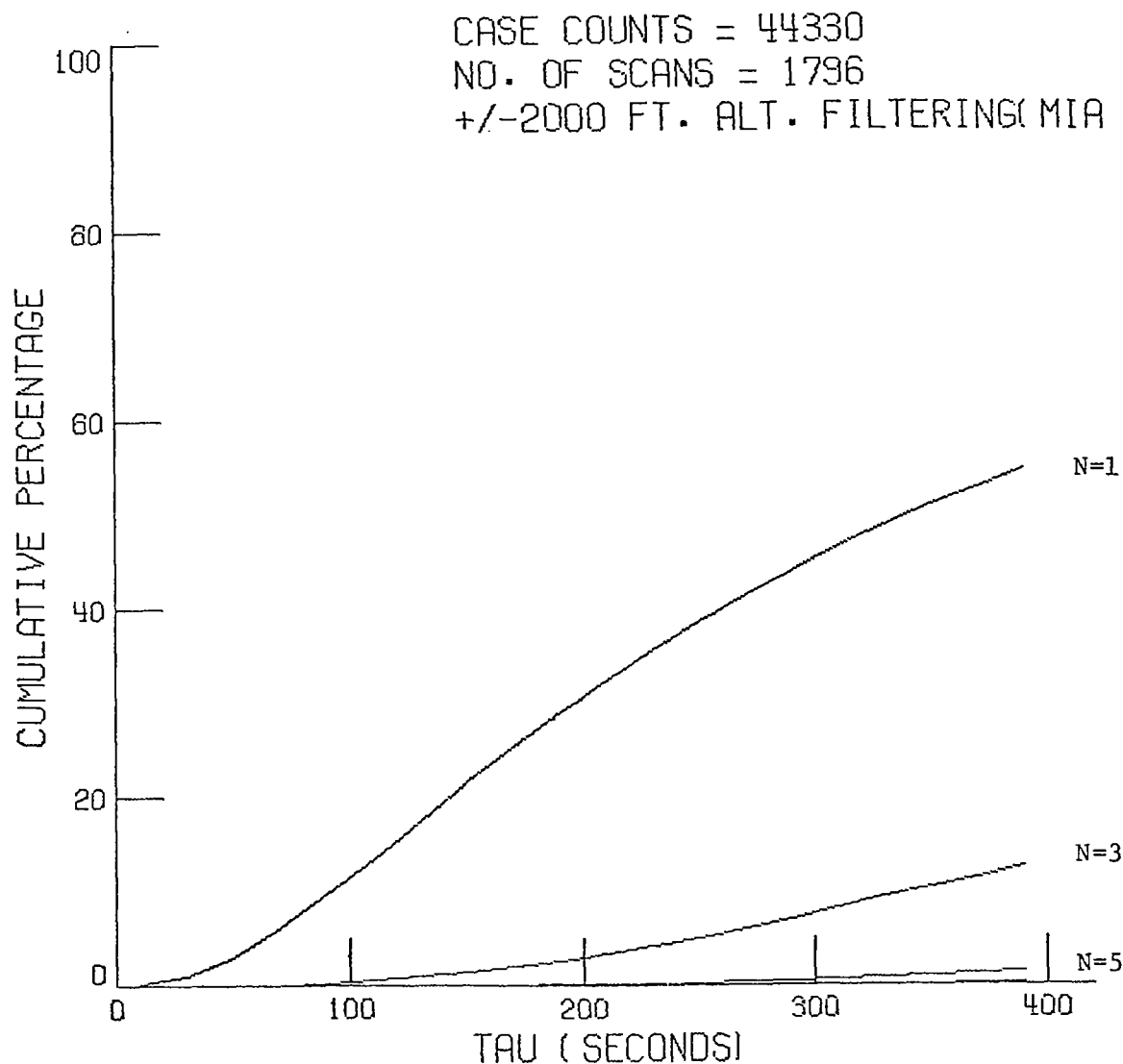axis. No other discrimination is used.   Atlanta #2 data.

Figure 7.32 Average percent of flying time that a randomly selected aircraft will simultaneously observe N other aircraft with a value of the Modified Tau parameter less than the value given along the horizontal axis. No other discrimination is used. Miami #1 data.
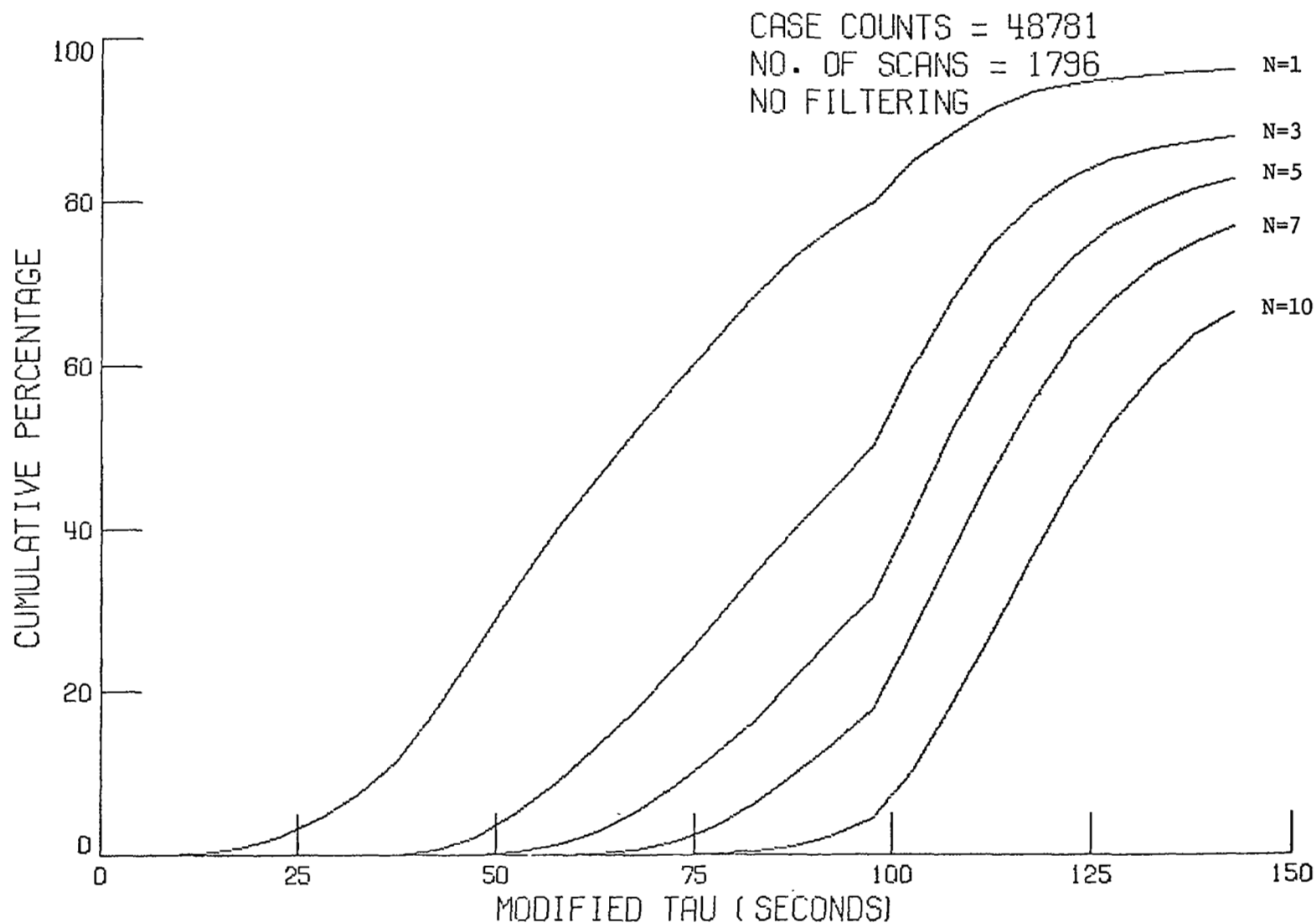
Figure 7.33 Average percent of flying time that a randomly selected aircraft will simultaneously observe N other aircraft with a value of the Modified Tau parameter less than the value given along the horizontal axis. No other discrimination is used. Miami #2 data.
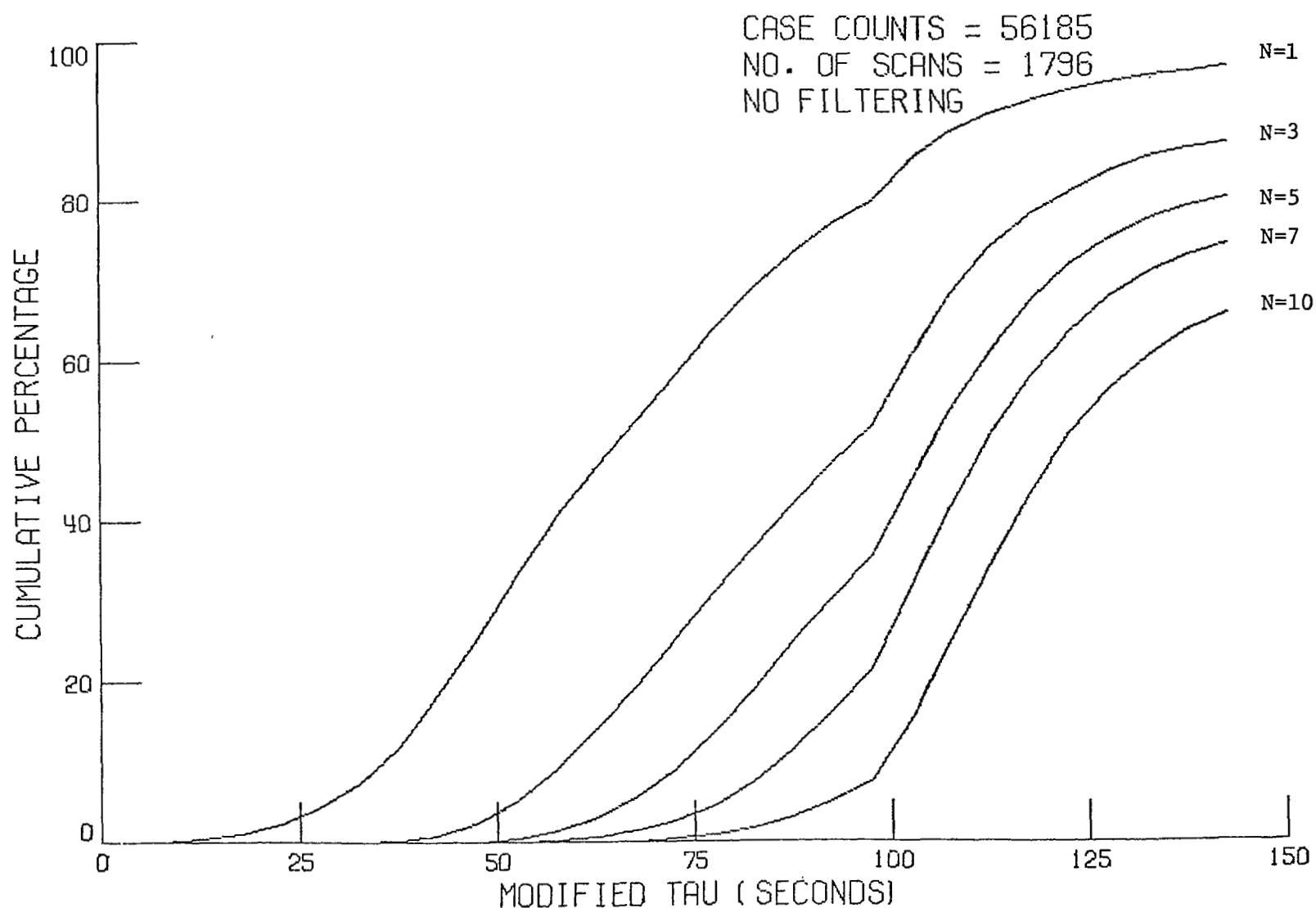
Figure 7.34 Average percent of flying time that a randomly selected aircraft
will simultaneously observe N other aircraft with a value of the
Modified Tau parameter less than the value given along the horizontal
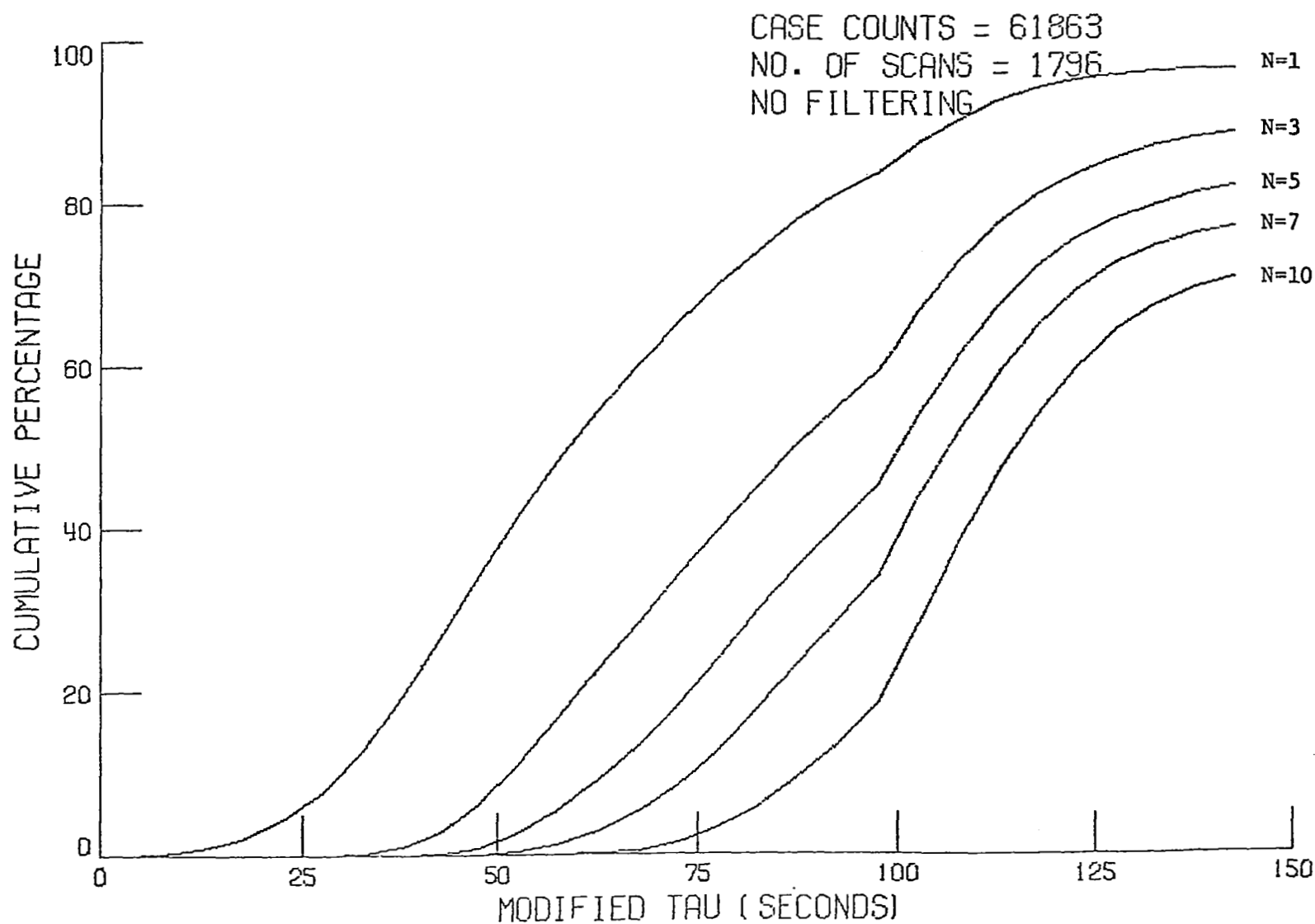axis. Altitude discrimination of ± 2000 feet. Atlanta #1 data.

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Figure 7.35 Average percent of flying time that a randomly selected aircraft will simultaneously observe N other aircraft with a value of the Modified Tau parameter less than the value given along the horizontal axis. Altitude discrimination of $\pm$ 2000 feet. Atlanta #2 data.
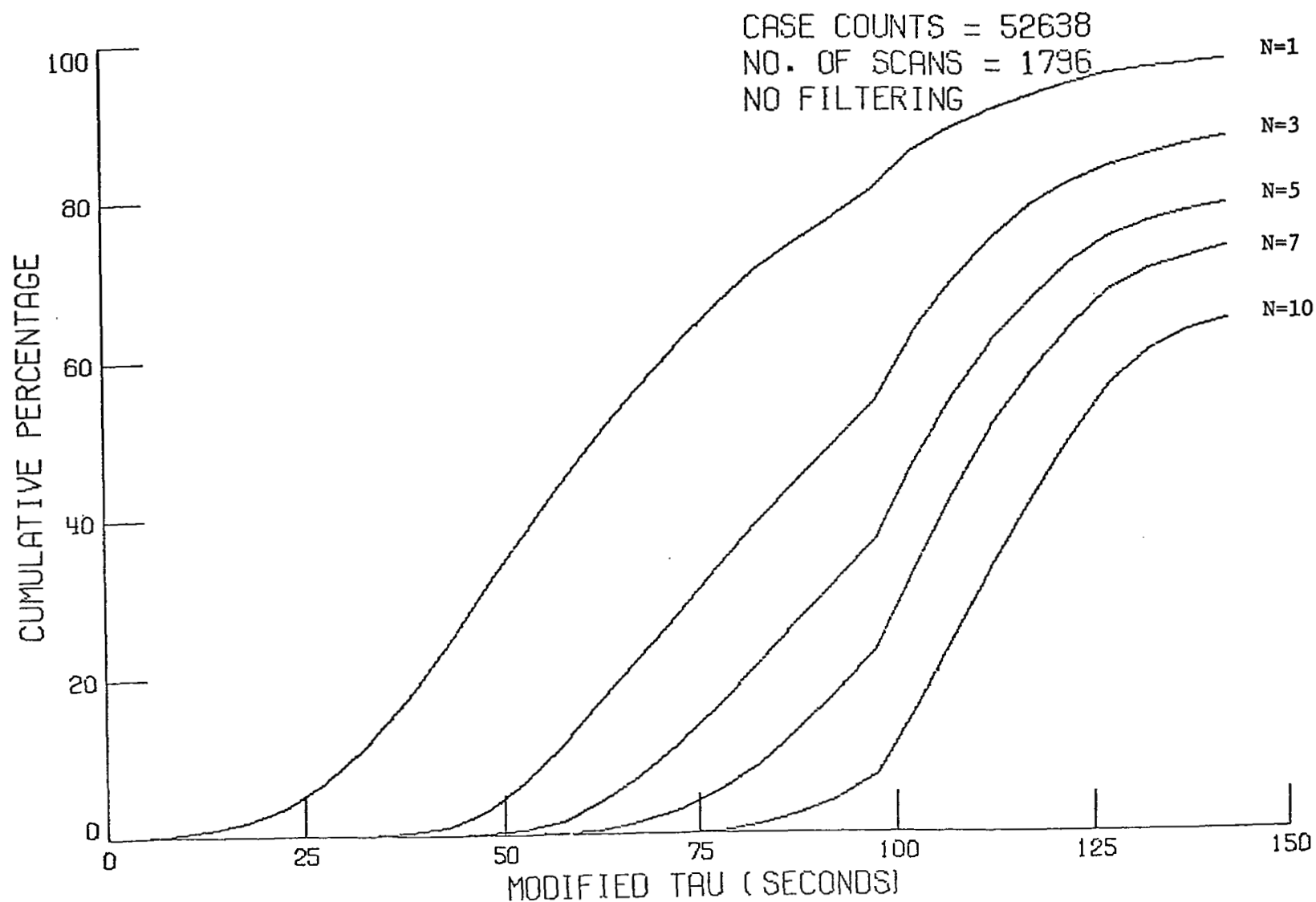
Figure 7.36 Average percent of flying time that a randomly selected aircraft
will simultaneously observe N other aircraft with a value of the
Modified Tau parameter less than the value given along the horizontal
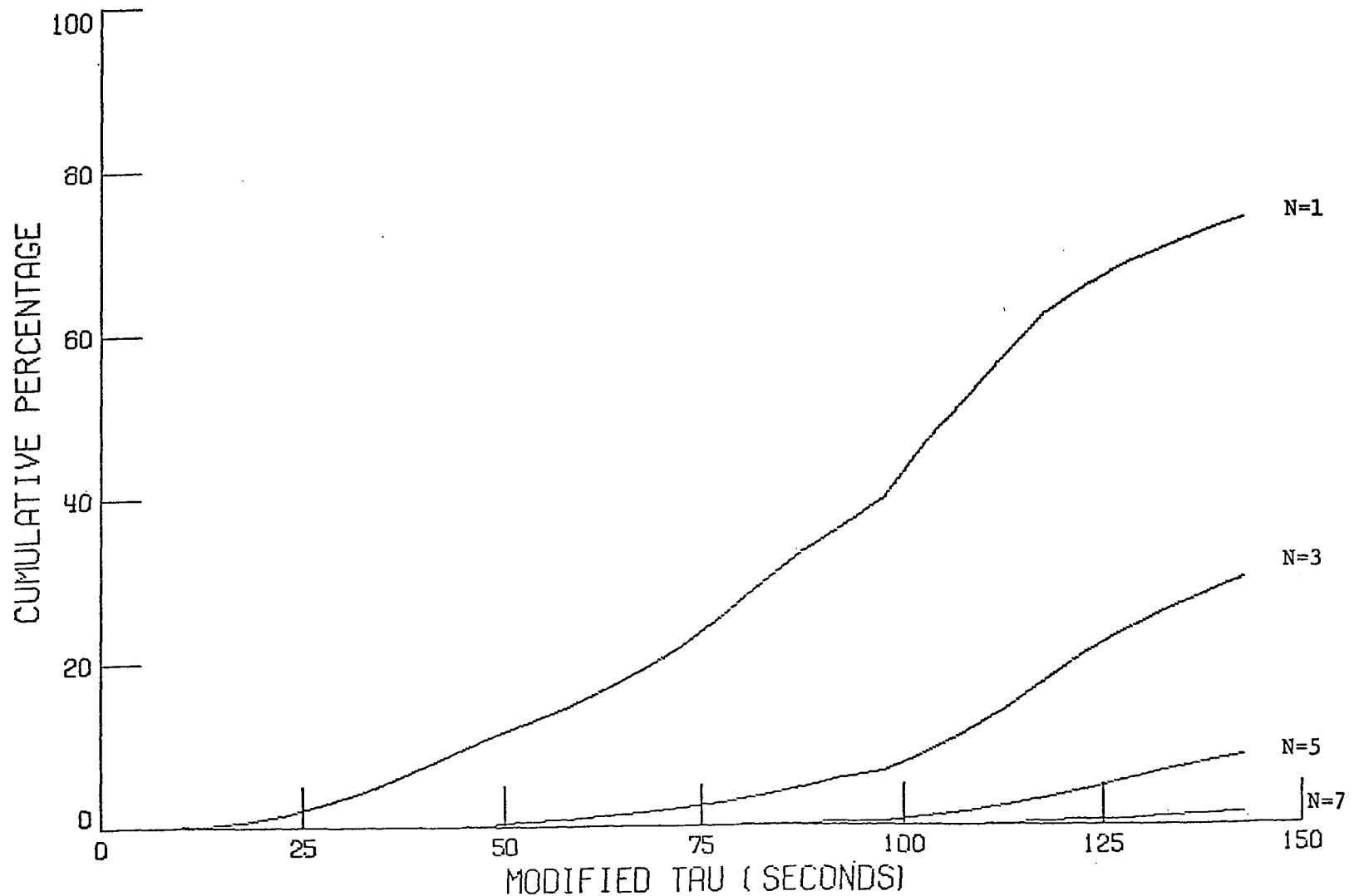axis. Altitude discrimination of ± 2000 feet. Miami #1 data.
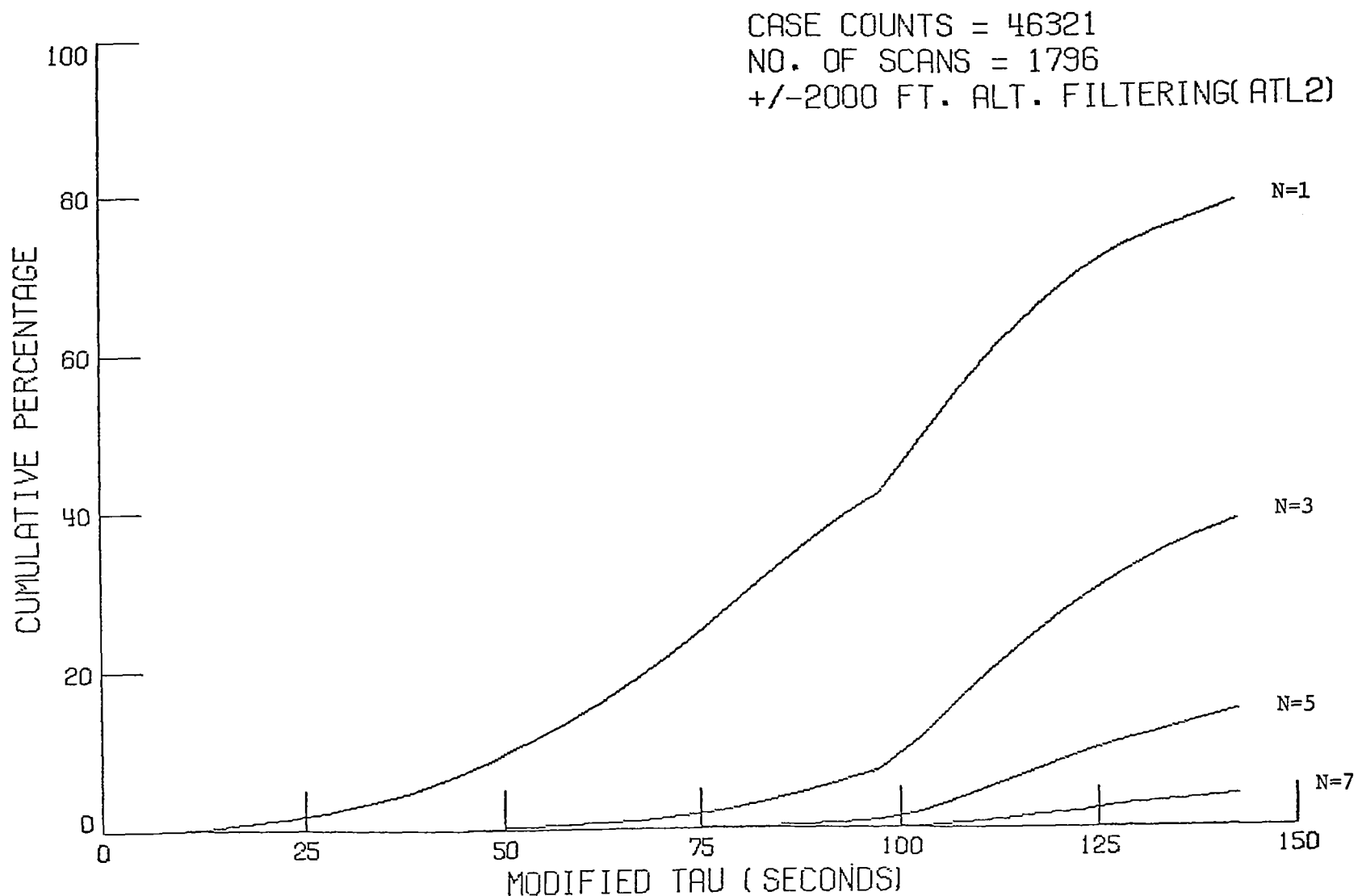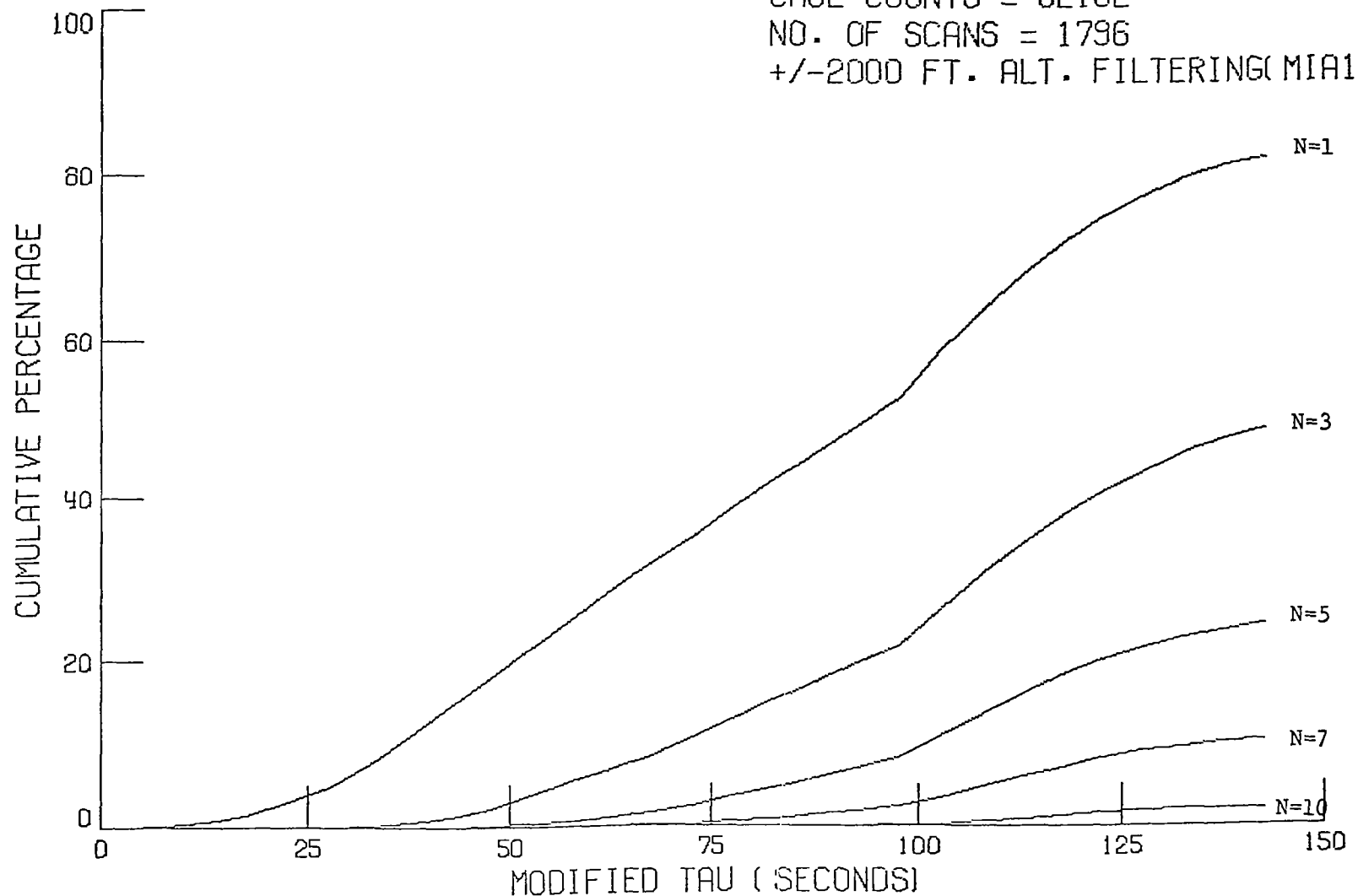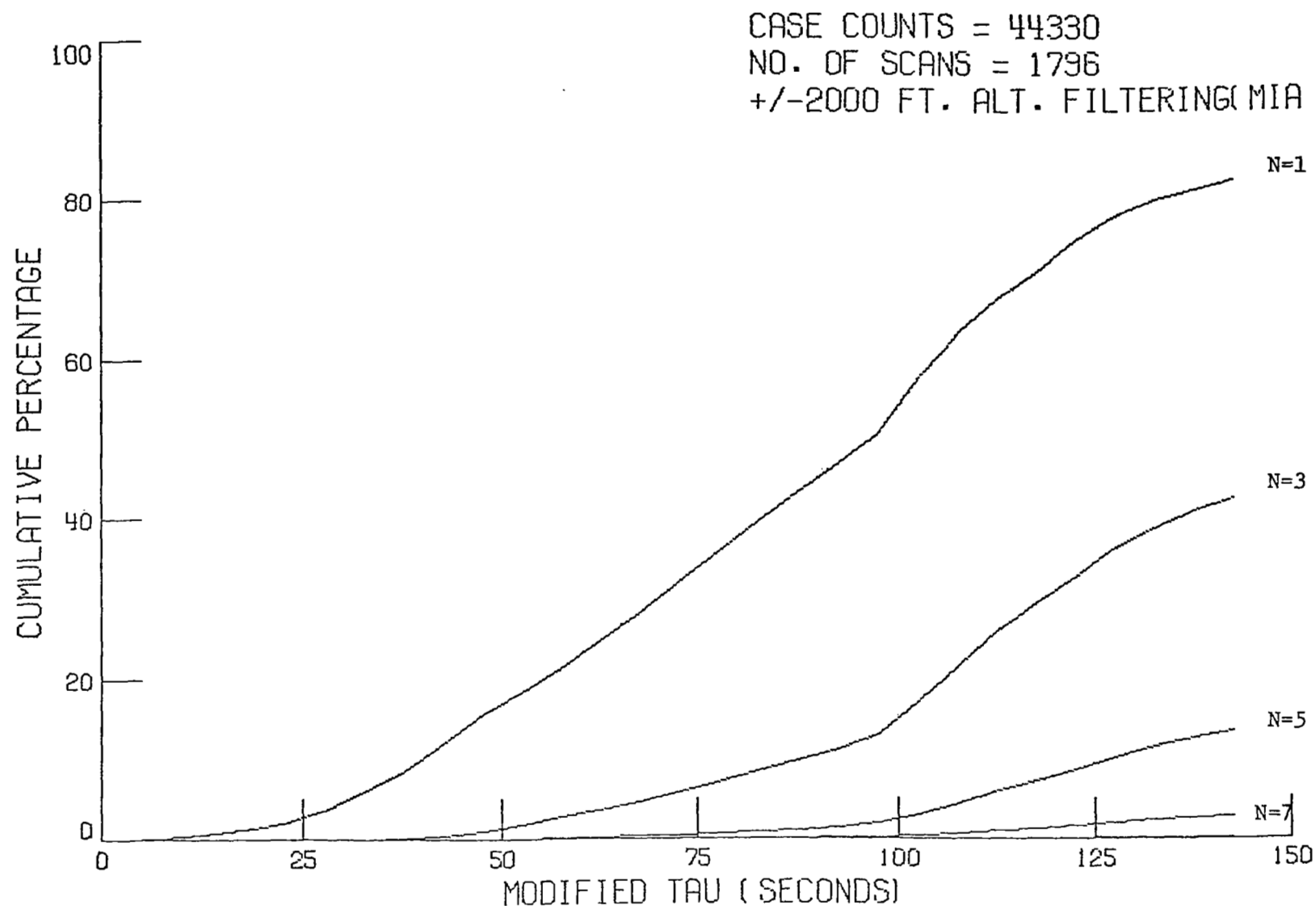
Figure 7.37 Average percentage of flying time that a randomly selected aircraft
will simultaneously observe N other aircraft with a value of the Modified
Tau parameter less than the value given along the horizontal axis.
Altitude discrimination of ± 2000 feet. Miami #2 data.

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16. Abstract

A Cockpit Display of Traffic Information (CDTI) is a cockpit instrument which provides information to the aircrew on the relative location of aircraft traffic in the vicinity of their aircraft (ownship). In addition, the CDTI may provide information to assist in navigation and in aircraft control. It is usually anticipated that the CDTI will be integrated with a horizontal situation indicator used for navigational purposes and/or with a weather radar display. In this study, several sets of aircraft traffic data are analyzed to determine statistics on the number of targets that will be displayed on a CDTI using various target selection criteria. Traffic data were obtained from an Atlanta Terminal Area Simulation and from radar tapes recorded at the Atlanta and Miami terminal areas. Results are given in the form of plots showing the average percentage of time (or probability) that an aircraft equipped with a CDTI would observe from 0 to 10 other aircraft on the display for range settings on the CDTI up to 30 n. mi. and using various target discrimination techniques.

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